Examination of Fernald Site

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Frank W. Schwartz March 8/94

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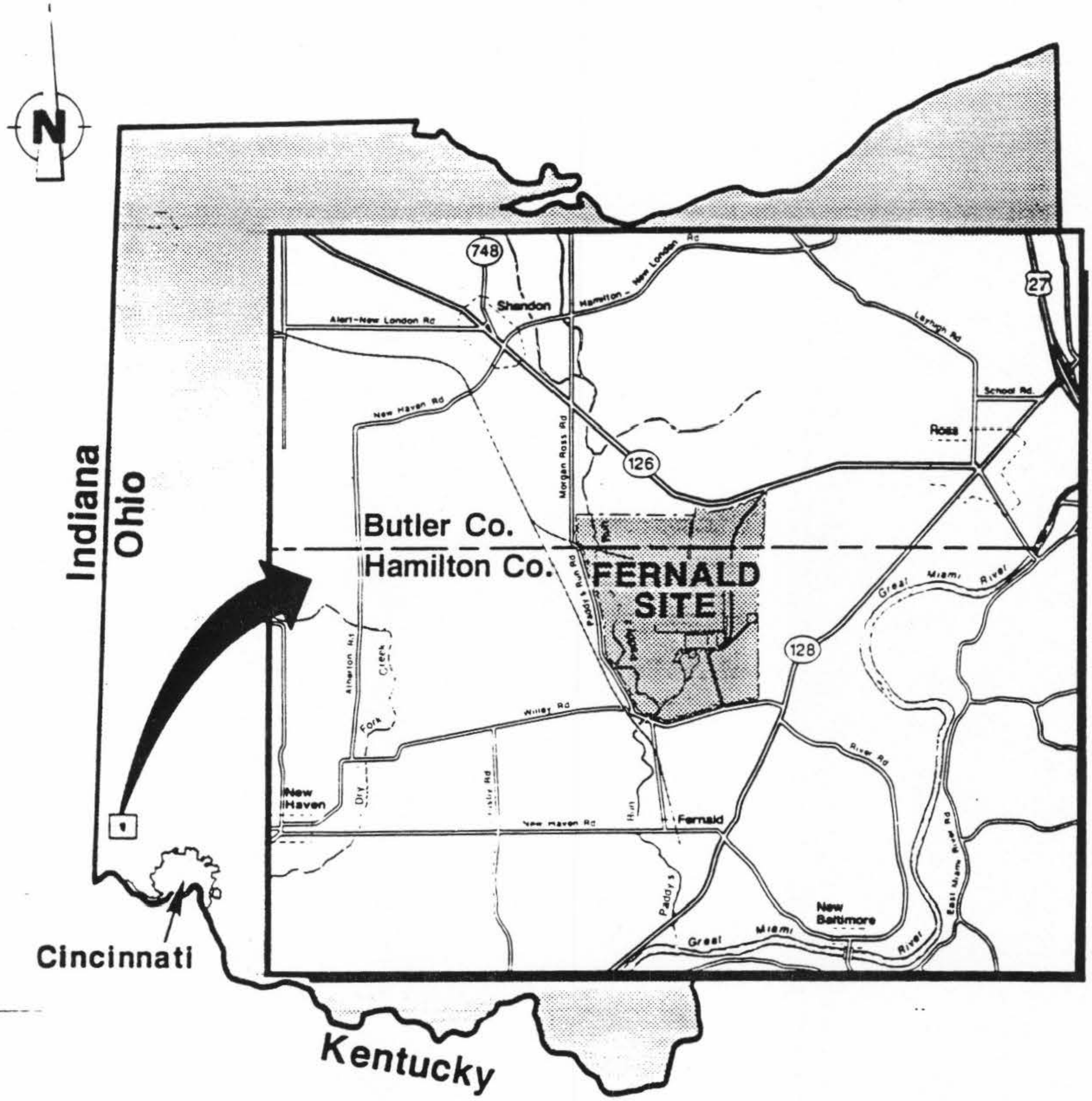
1.0 INTRODUCTION TO SITE:

The Fernald Environmental Management Project (FEMP) is located approximately 17 miles northwest of Cincinnati, Ohio. Figure 1-1 depicts the FEMP location. The FEMP lies on 1050 acres in a rural area of Hamilton and Butler counties. The Fernald site produced high quality uranium metals for forty years for military use and is owned by the Department of Energy. The Department of Energy suspended production in July 1989 and formally ended it in 1991. Up to 1984 solid and slurried waste was disposed of on the site. The Fernald layout is depicted in Figure 1-2 and Table 1-1. The focus of the Department of Energy now is the environmental restoration of the area.

Within a five mile radius of FEMP are several villages and scattered residences. The majority of land use in the area is farming and raising dairy and beef cattle. The concern of this report is to examine the local geology and lithology, hydrogeology, hydrology, extent of uranium contaminated groundwater and run tests on reported pumping test data from south plume area.

Figure 1-1: FEMP Location and Vicinity



The Fernald Site covers about 425 hectares (1,050 acres).

Figure 1-2: Fernald Layout

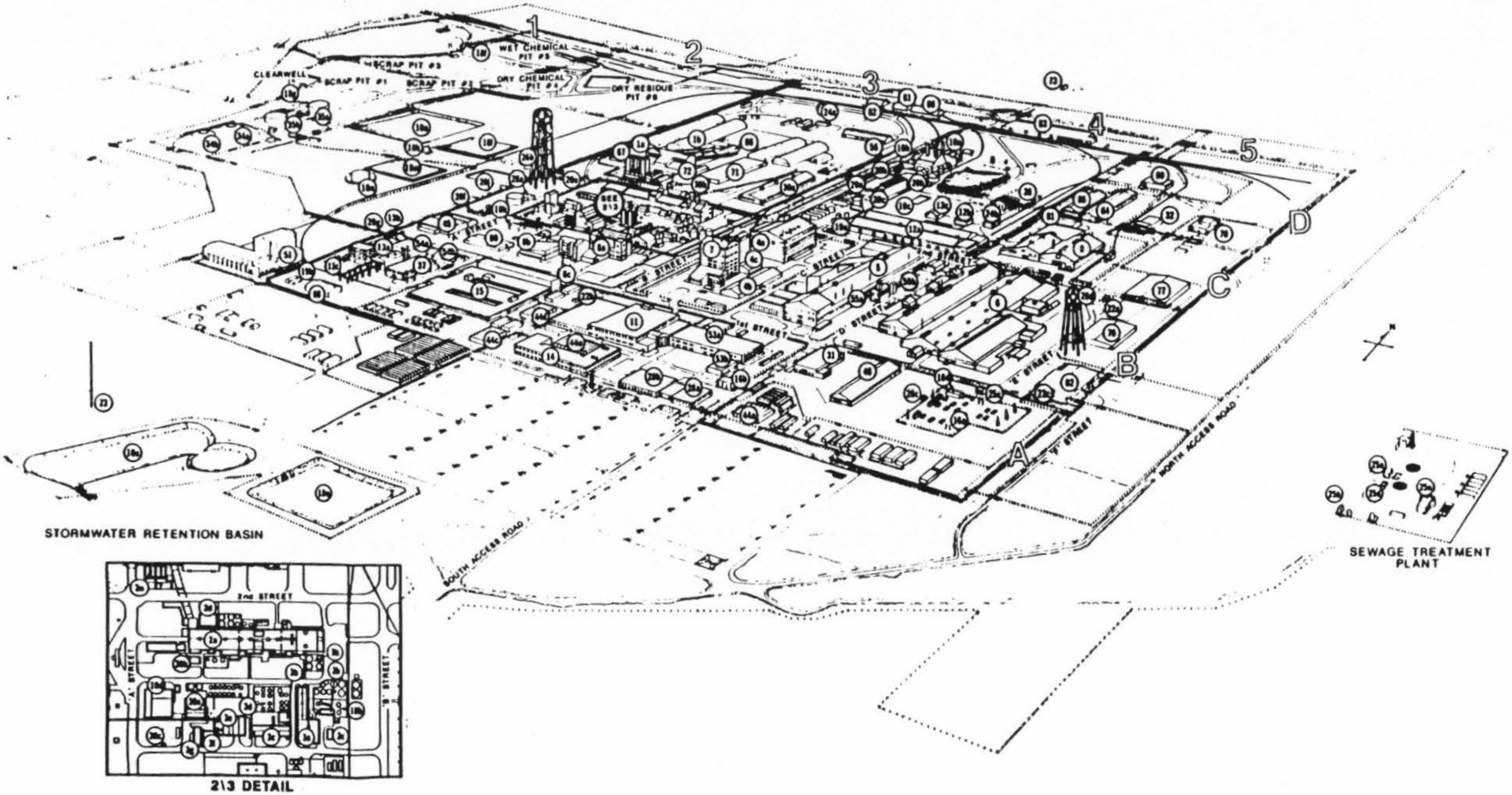


Table 1-1
Building Identification

Building ID No.	Grid Coordinates	Title
00	**	General
1a	C-3	Preparation Plant
1b	C-3	Plant 1 Storage Building
2a	B-3	Ore Refinery Plant
2b	B-3	Lime Handling Building
2c	B-3	Bulk Lime Handling Building
2d	B-3	Metal Dissolver Building
2e	C-3	NFS Storage and Pump House
3a	B-3	Maintenance Building
3b	B-3	Ozone Building
3c	B-3	Control House
3d	B-3	NAR Towers
3e	B-3	Hot Raffinate Building
3f	B-3	Digestion Fume Recovery
3g	B-3	Refrigeration Building
3h	B-3	Refinery Sump
4a	B-4	Green Salt Plant
4b	B-4	Plant 4 Warehouse
4c	B-4	Plant 4 Maintenance Building
5	B-4	Metals Production Plant
6	B-5	Metals Fabrication Plant
7	B-4	Plant 7
8a	B-3	Recovery Plant
8b	B-3	Maintenance Building
8c	B-3	Rotary Kiln/Drum Reconditioning
9	C-5	Special Products Plant
10a	D-4	Boiler Plant
10b	D-4	Boiler Plant Maintenance Building
11	A-4	Service Building
12a	C-4	Maintenance Building (Main)
12b	C-4	Cylinder Storage Building
12c	C-4	Lumber Storage Building
13a	A-3	Pilot Plant Wet Side
13b	A-3	Pilot Plant Maintenance Building
13c	A-3	Sump Pump House
14	A-4	Administration Building
15	A-3	Laboratories
16a	A-5	Main Electrical Station
16b	A-4	Electrical Substation
18a	C-2	Biodenitrification Surge Lagoon
18b	C-3	General Sump
18c	C-4	Coal Pile Runoff Basin
18d	B-3	Biodenitrification Towers
18e	*	Stormwater Retention Basin
18f	D-1	Pit 5 Sluice Gate
18g	C-1	Clearwell Pump House
18h	B-3	BDN Effluent Treatment Facility
18k	B-2	Methanol Tank
18l	C-2	Low Nitrate Tank
18m	B-2	High Nitrate Tank
18n	B-2	High Nitrate Storage Tank
19a	C-4	Main Metal Tank Farm
19b	A-3	Pilot Plant Ammonia Tank Farm
20a	C-4	Pump Station and Power Center
20b	D-4	Water Plant
20c	C-4	Cooling Towers
20d	B-5	Elevated Storage Tank (Potable H_2O)
20e	B-3	Well House #1
20f	B-3	Well House #2
20g	A-3	Well House #3
20h	D-4	Process Water Storage Tank
20j	B-2	Lime Slurry Pits
22a	B-5	Gas Meter Building
22b	A-3	Storm Sewer Lift Station
22c	A-5	Truck Scale
23	*	Meteorological Tower
24a	C-3	Railroad Scale House
24b	C-4	Railroad Engine Building
25a	*	Chlorination Building
25b	*	Manhole-175
25c	A-5	Sewage Lift Station Building
25d	*	U.V. Disinfection Building
25e	*	Digester Control Building
26a	B-3	Pump House – H.P. Fire Protection
26b	B-3	Elevated Water Storage Tank
28a	A-4	Security Building
28b	A-4	Human Resources Building
30a	C-3	Chemical Warehouse
30b	C-3	Drum Storage Warehouse
31	A-5	Engine House – Garage
32	D-5	Magnesium Storage
34a	B-1	K-65 Storage Tank – North
34b	B-1	K-65 Storage Tank – South
35a	C-1	Metal Oxide Storage Tank – North
35b	B-1	Metal Oxide Storage Tank – South
37	A-3	Pilot Plant Annex
38	D-4	Propane Storage
39a	B-3	Incinerator Building
39b	B-3	Shelter Storage Building
39c	B-3	Incinerator Building Sprinkler Riser House
44a	A-5	Trailer Complex — 6-Plex (East)
44c	A-3	Trailer Complex — 7-Plex (South)
44d	A-3	Trailer Complex — 7-Plex (North)
44e	A-4	Trailer Complex — 10-Plex
45	B-3	Rust Engineering Building
46	A-5	Heavy Equipment Garage
51	A-2	UF_6 to UF_4 Reduction Facility II
53a	A-4	Occupational Safety & Health
53b	A-4	In-Vivo Building
54a	A-3	UF_6 to UF_4 Reduction Facility I
54b	A-3	Pilot Plant Warehouse
55a	B-4	Lag Recycling Plant
55b	B-4	Lag Recycling Pit/Elevator
56	D-3	[illegible] Storage Warehouse
60	D-3	Quonset Hut #1
61	D-3	Quonset Hut #2
62	D-3	Quonset Hut #3
63	D-4	KC-2 Warehouse
64	D-5	Thorium Warehouse
65	D-5	(Old) Plant 5 Warehouse
66	C-3	Drum Reconditioning Building
67	C-3	Plant 1 Thorium Warehouse
68	A-3	Pilot Plant Warehouse
69	D-5	Decontamination Building
71	C-3	General In-Process Storage Warehouse
72	C-3	Drum Storage Building
73	*	Fire Brigade Training Center Building
77	C-5	Finished Products Warehouse
78	*	New D&D Facility
79	B-5	Plant 6 Warehouse
80	B-3	Plant 8 Warehouse
81	C-5	Plant 9 Warehouse
82	B-5	Receiving & Incoming Materials Inspection Area

* Outside of Perimeter Security Fence

** NOTE. Any Unidentified Area is Referred to as 00 General

2.0 LOCAL GEOLOGY:

Bedrock underlying Femp consists of predominately fine grained, interbedded clayey and silt rich shale with alternating thin layers of limestone. The strata is recognized as the Cincinnatian Series. The shale bedrock was cut into by an ancient river 60 meters (200 feet) below the Great Miami River, which formed a channel named the New Haven Trough. During the Pleistocene the trough was filled in with sand and gravel sediments from glacial movement. This is known as the Great Miami Aquifer. The last of the glaciers deposited a relatively impermeable glacial till over the sand and gravel sediment. This 5glacial overburden ranges from 5 to 50 feet in thickness, but is commonly between 20 and 30 feet. The glacial overburden is unevenly deposited throughout the FEMP area and consists of sand, gravel, clay, silt and cobble. A generalized stratigraphic column of the valley fill deposit is depicted in Figure 2-1.

The overburden has been significantly eroded and left terrace remnants by the Great Miami River and its tributaries. The terrace remnants stand higher than surrounding bottom land of the river valley. Above the terrace remnants, about 177 meters (580 feet) above sea level lies the Fernald site. The land slopes downward from the northern boundary, 213 meters (700 feet) to Paddys Run, 168 meters (500 feet).

The portion of the Great Miami Aquifer that underlies the Fernald site consists mainly of glaciofluvial sand and gravel outwash. The deposits lie unconformably on the shale bedrock,

Figure 2-1
Generalized Stratigraphic Column of FEMP Area

AGE	LITHOLOGIC SYMBOL	THICKNESS, FEET	DESCRIPTION OF DEPOSIT/ROCK UNIT
HOLOCENE		1-5	SILT AND SILTY SOIL MIXTURES. LACUSTRINE DEPOSITS ALSO PRESENT IN SOME AREAS.
PLEISTOCENE		1-60	GLACIAL OVERBURDEN CONSISTING PREDOMINANTLY OF YELLOWISH TO GRAYISH-BROWN SILTY CLAY WITH SOME GRAVEL. LENSES OF SILTY SAND.
		40-100	GLACIAL OUTWASH DEPOSITS CONTAINING SAND AND GRAVEL. LENSES OF SAND ALSO PRESENT.
		10-20	STIFF OLIVE-GRAY CLAY DIVIDING GLACIAL OUTWASH DEPOSITS. KNOWN AS CLAY INTERBED.
		40-60	GLACIAL OUTWASH DEPOSITS CONTAINING SAND AND GRAVEL.
			UNCONFORMITY
ORDOVICIAN		800	OLIVE-GRAY SHALE WITH INTERBEDDED LIMESTONE. MEMBER OF THE CINCINNATIAN SERIES.

filling the bedrock to a depth of 200 feet in places. The thickness of the aquifer varies from 120 to 200 feet in the valley and tributary valley centers to only a few feet along the valley walls in the FEMP area. In the heterogeneous glaciofluvial deposits, there are minor amounts of silt and clay in the well sorted sand and gravel. Most of the FEMP area has an interbedded clay layer within the coarse gravel of the Great Miami Aquifer. The clay layer is roughly 1 to 20 feet thick and is about 60 to 80 feet below the water table. It consists of an impermeable homogeneous clay which act as an aquitard within the Great Miami Aquifer. The aquifer is divided into lower and upper halves due to the interbed. The interbed pinches out in the south and east of the FEMP area.

2.1 <u>GEOLOGIC TRENDS</u>:

Cross Sections of the Great Miami Aquifer are depicted in Figures 2-3 through 2-7, while Figure 2-2 shows the location of the geologic cross sections. Due to having numerous bore holes the aquifer is shown in great detail with fairly certain accuracy.

Cross section A-A′ (Figure 2-3) depicts the underlying geology of the FEMP. This cross section obliquely cuts the bedrock with the thickness of the section fairly constant, averaging between 150 to 200 feet. In the western halve the clay interbed is present. The B-B′ cross section (Figure 2-4) is also underlying the FEMP, and is roughly perpendicular to cross

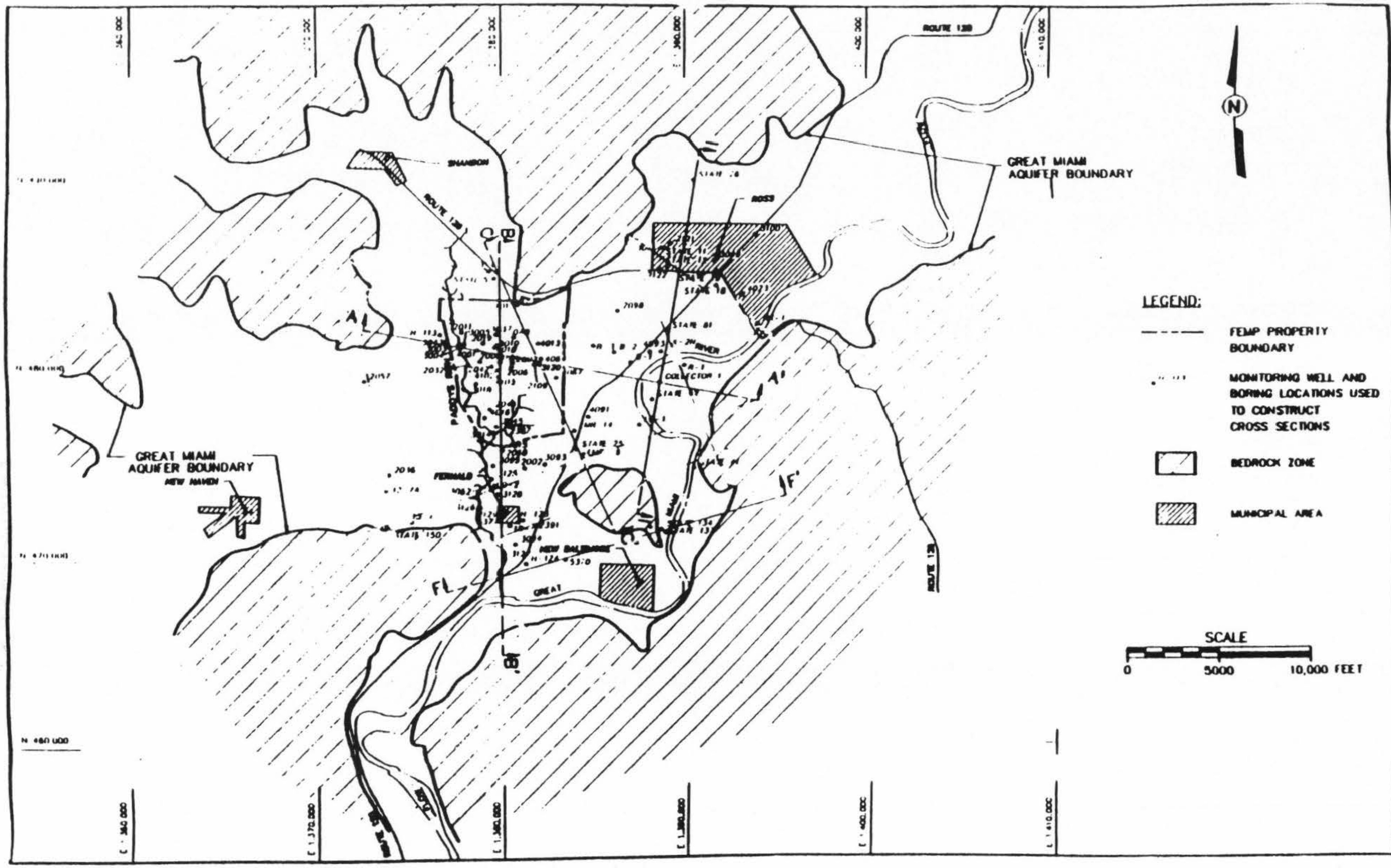


Figure 2-2
Location of Hydrogeologic Environments

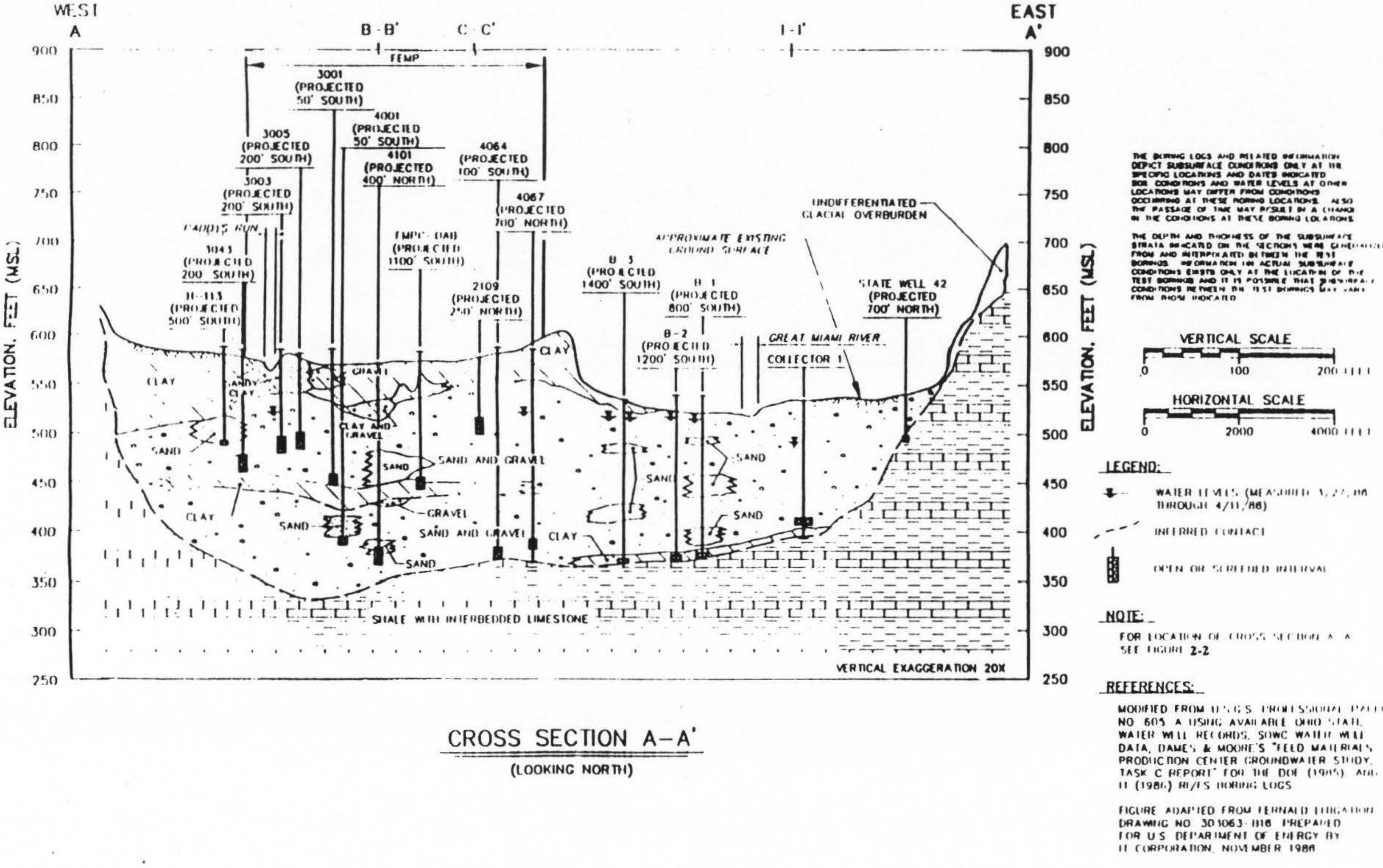

WEST
A
EAST
A'
B-B'
C-C'
I-I'
FEMP
ELEVATION, FEET (MSL)
900
850
800
750
700
650
600
550
500
450
400
350
300
250
3001 (PROJECTED 50' SOUTH)
4001 (PROJECTED 50' SOUTH)
4101 (PROJECTED 400' NORTH)
3005 (PROJECTED 200' SOUTH)
3003 (PROJECTED 200' SOUTH)
4064 (PROJECTED 100' SOUTH)
4067 (PROJECTED 700' NORTH)
PADDYS RUN
3043 (PROJECTED 200' SOUTH)
11-113 (PROJECTED 500' SOUTH)
FMPC-DAB (PROJECTED 1100' SOUTH)
2109 (PROJECTED 250' NORTH)
B-3 (PROJECTED 1400' SOUTH)
B-1 (PROJECTED 800' SOUTH)
B-2 (PROJECTED 1200' SOUTH)
APPROXIMATE EXISTING GROUND SURFACE
UNDIFFERENTIATED GLACIAL OVERBURDEN
STATE WELL 42 (PROJECTED 700' NORTH)
GREAT MIAMI RIVER
COLLECTOR 1
CLAY
SANDY CLAY
GRAVEL
CLAY AND GRAVEL
SAND
SAND AND GRAVEL
SHALE WITH INTERBEDDED LIMESTONE
VERTICAL EXAGGERATION 20X
CROSS SECTION A-A'
(LOOKING NORTH)
THE BORING LOGS AND RELATED INFORMATION DEPICT SUBSURFACE CONDITIONS ONLY AT THE SPECIFIC LOCATIONS AND DATES INDICATED. SOIL CONDITIONS AND WATER LEVELS AT OTHER LOCATIONS MAY DIFFER FROM CONDITIONS OCCURRING AT THESE BORING LOCATIONS. ALSO THE PASSAGE OF TIME MAY RESULT IN A CHANGE IN THE CONDITIONS AT THESE BORING LOCATIONS.
THE DEPTH AND THICKNESS OF THE SUBSURFACE STRATA INDICATED ON THE SECTIONS WERE GENERALIZED FROM AND INTERPOLATED BETWEEN THE TEST BORINGS. INFORMATION ON ACTUAL SUBSURFACE CONDITIONS EXISTS ONLY AT THE LOCATION OF THE TEST BORINGS AND IT IS POSSIBLE THAT SUBSURFACE CONDITIONS BETWEEN THE TEST BORINGS MAY VARY FROM THOSE INDICATED.
VERTICAL SCALE
0
100
200 FEET
HORIZONTAL SCALE
0
2000
4000 FEET
LEGEND:
WATER LEVELS (MEASURED 3/27/88 THROUGH 4/11/88)
INFERRED CONTACT
OPEN OR SCREENED INTERVAL
NOTE:
FOR LOCATION OF CROSS SECTION A-A SEE FIGURE 2-2
REFERENCES:
MODIFIED FROM U.S.G.S. PROFESSIONAL PAPER NO. 605-A USING AVAILABLE OHIO STATE WATER WELL RECORDS, SOWC WATER WELL DATA, DAMES & MOORE'S "FEED MATERIALS PRODUCTION CENTER GROUNDWATER STUDY, TASK C REPORT" FOR THE DOE (1985), AND IT (1986) RI/FS BORING LOGS
FIGURE ADAPTED FROM FERNALD LITIGATION DRAWING NO. 301063-B18 PREPARED FOR U.S. DEPARTMENT OF ENERGY BY IT CORPORATION, NOVEMBER 1988

Figure 2-3

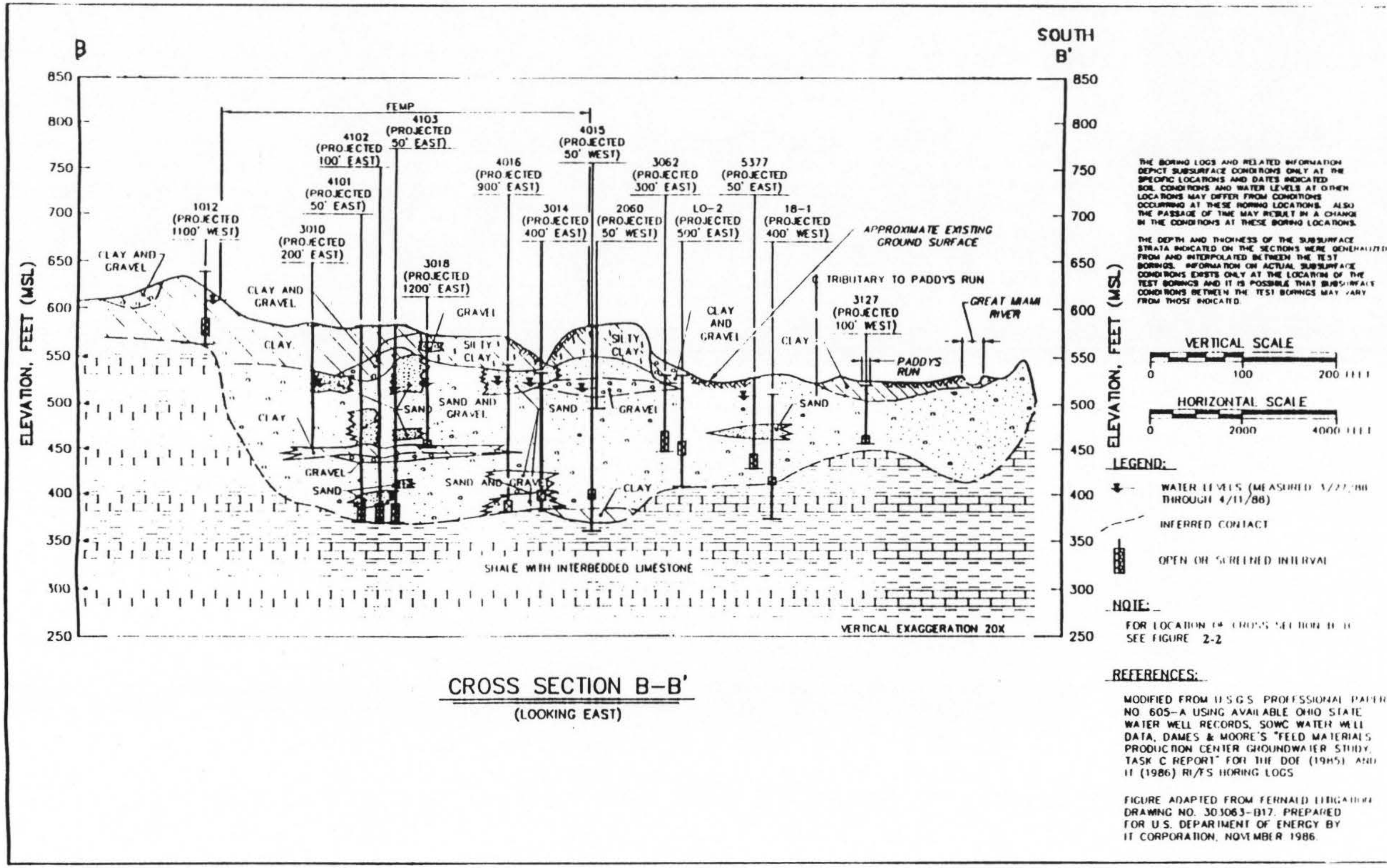
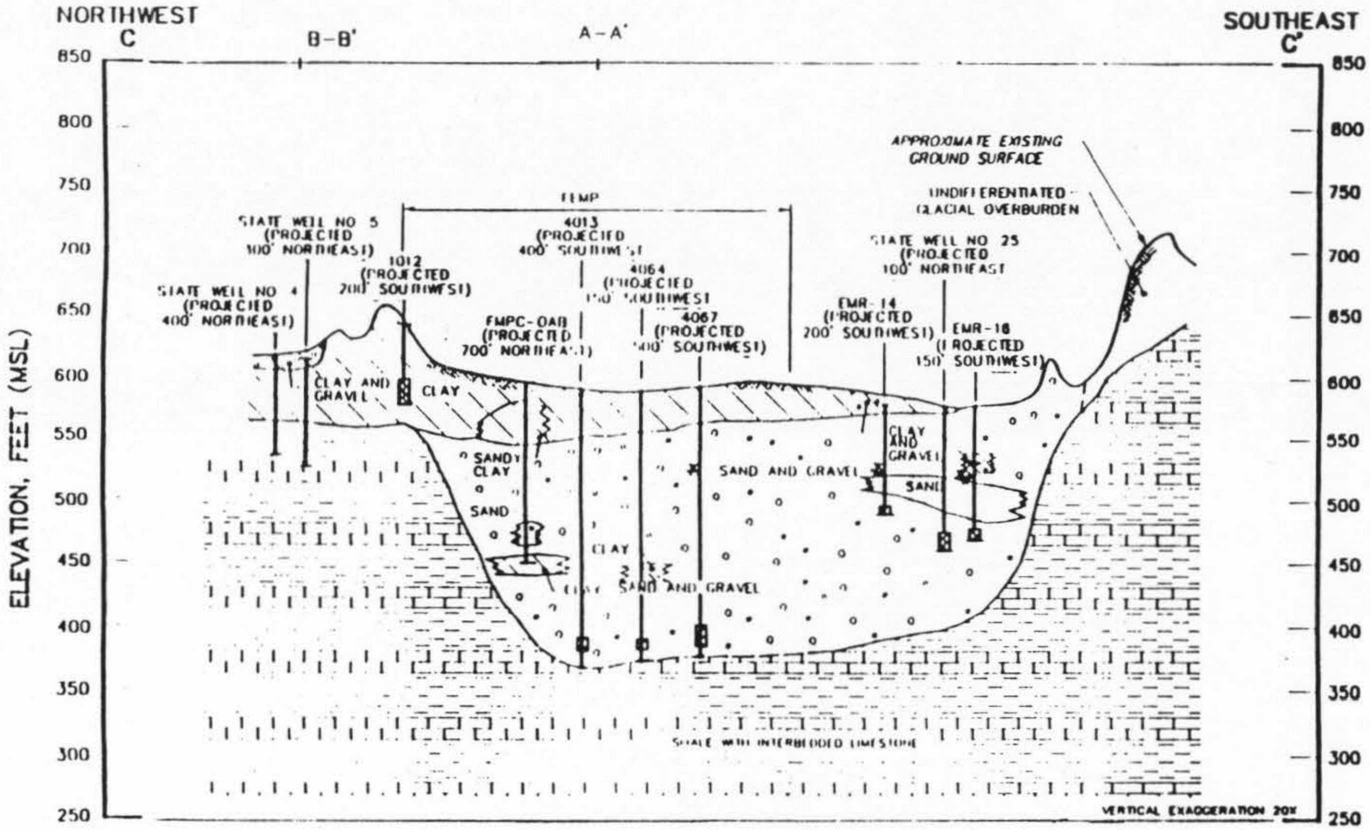

B
SOUTH
B'
ELEVATION, FEET (MSL)
850
800
750
700
650
600
550
500
450
400
350
300
250
FEMP
1012 (PROJECTED 1100' WEST)
3010 (PROJECTED 200' EAST)
4101 (PROJECTED 50' EAST)
4102 (PROJECTED 100' EAST)
4103 (PROJECTED 50' EAST)
3018 (PROJECTED 1200' EAST)
4016 (PROJECTED 900' EAST)
3014 (PROJECTED 400' EAST)
4015 (PROJECTED 50' WEST)
2060 (PROJECTED 50' WEST)
3062 (PROJECTED 300' EAST)
LO-2 (PROJECTED 500' EAST)
5377 (PROJECTED 50' EAST)
18-1 (PROJECTED 400' WEST)
3127 (PROJECTED 100' WEST)
APPROXIMATE EXISTING GROUND SURFACE
TRIBUTARY TO PADDYS RUN
PADDYS RUN
GREAT MIAMI RIVER
CLAY AND GRAVEL
CLAY
SILTY CLAY
GRAVEL
SAND
SAND AND GRAVEL
SHALE WITH INTERBEDDED LIMESTONE
VERTICAL EXAGGERATION 20X
THE BORING LOGS AND RELATED INFORMATION DEPICT SUBSURFACE CONDITIONS ONLY AT THE SPECIFIC LOCATIONS AND DATES INDICATED. SOIL CONDITIONS AND WATER LEVELS AT OTHER LOCATIONS MAY DIFFER FROM CONDITIONS OCCURRING AT THESE BORING LOCATIONS. ALSO THE PASSAGE OF TIME MAY RESULT IN A CHANGE IN THE CONDITIONS AT THESE BORING LOCATIONS.
THE DEPTH AND THICKNESS OF THE SUBSURFACE STRATA INDICATED ON THE SECTIONS WERE GENERALIZED FROM AND INTERPOLATED BETWEEN THE TEST BORINGS. INFORMATION ON ACTUAL SUBSURFACE CONDITIONS EXISTS ONLY AT THE LOCATION OF THE TEST BORINGS AND IT IS POSSIBLE THAT SUBSURFACE CONDITIONS BETWEEN THE TEST BORINGS MAY VARY FROM THOSE INDICATED.
VERTICAL SCALE
0 100 200 FEET
HORIZONTAL SCALE
0 2000 4000 FEET
LEGEND:
WATER LEVELS (MEASURED 3/22/88 THROUGH 4/11/88)
INFERRED CONTACT
OPEN OR SCREENED INTERVAL
NOTE:
FOR LOCATION OF CROSS SECTION B-B' SEE FIGURE 2-2
REFERENCES:
MODIFIED FROM U.S.G.S. PROFESSIONAL PAPER NO. 605-A USING AVAILABLE OHIO STATE WATER WELL RECORDS, SOWC WATER WELL DATA, DAMES & MOORE'S "FEED MATERIALS PRODUCTION CENTER GROUNDWATER STUDY, TASK C REPORT" FOR THE DOE (1985) AND IT (1986) RI/FS BORING LOGS
FIGURE ADAPTED FROM FERNALD LITIGATION DRAWING NO. 303063-B17, PREPARED FOR U.S. DEPARTMENT OF ENERGY BY IT CORPORATION, NOVEMBER 1986.
CROSS SECTION B-B'
(LOOKING EAST)

Figure 2-4



CROSS SECTION C–C'

(LOOKING NORTHEAST)

THE BORING LOGS AND RELATED INFORMATION DEPICT SUBSURFACE CONDITIONS ONLY AT THE SPECIFIC LOCATIONS AND DATES INDICATED. SOIL CONDITIONS AND WATER LEVELS AT OTHER LOCATIONS MAY DIFFER FROM CONDITIONS OCCURRING AT THESE BORING LOCATIONS. ALSO, THE PASSAGE OF TIME MAY RESULT IN A CHANGE IN THE CONDITIONS AT THESE BORING LOCATIONS.

THE DEPTH AND THICKNESS OF THE SUBSURFACE STRATA INDICATED ON THE SECTIONS WERE GENERALIZED FROM AND INTERPOLATED BETWEEN THE TEST BORINGS. INFORMATION ON ACTUAL SUBSURFACE CONDITIONS EXISTS ONLY AT THE LOCATION OF THE TEST BORINGS AND IT IS POSSIBLE THAT SUBSURFACE CONDITIONS BETWEEN THE TEST BORINGS MAY VARY FROM THOSE INDICATED.

VERTICAL SCALE: 0 100 200 FEET

HORIZONTAL SCALE: 0 2000 4000 FEET

LEGEND:

- WATER LEVELS (MEASURED 3/27/86 THROUGH 4/11/86)
- INFERRED CONTACT
- OPEN OR SCREENED INTERVAL

NOTE:

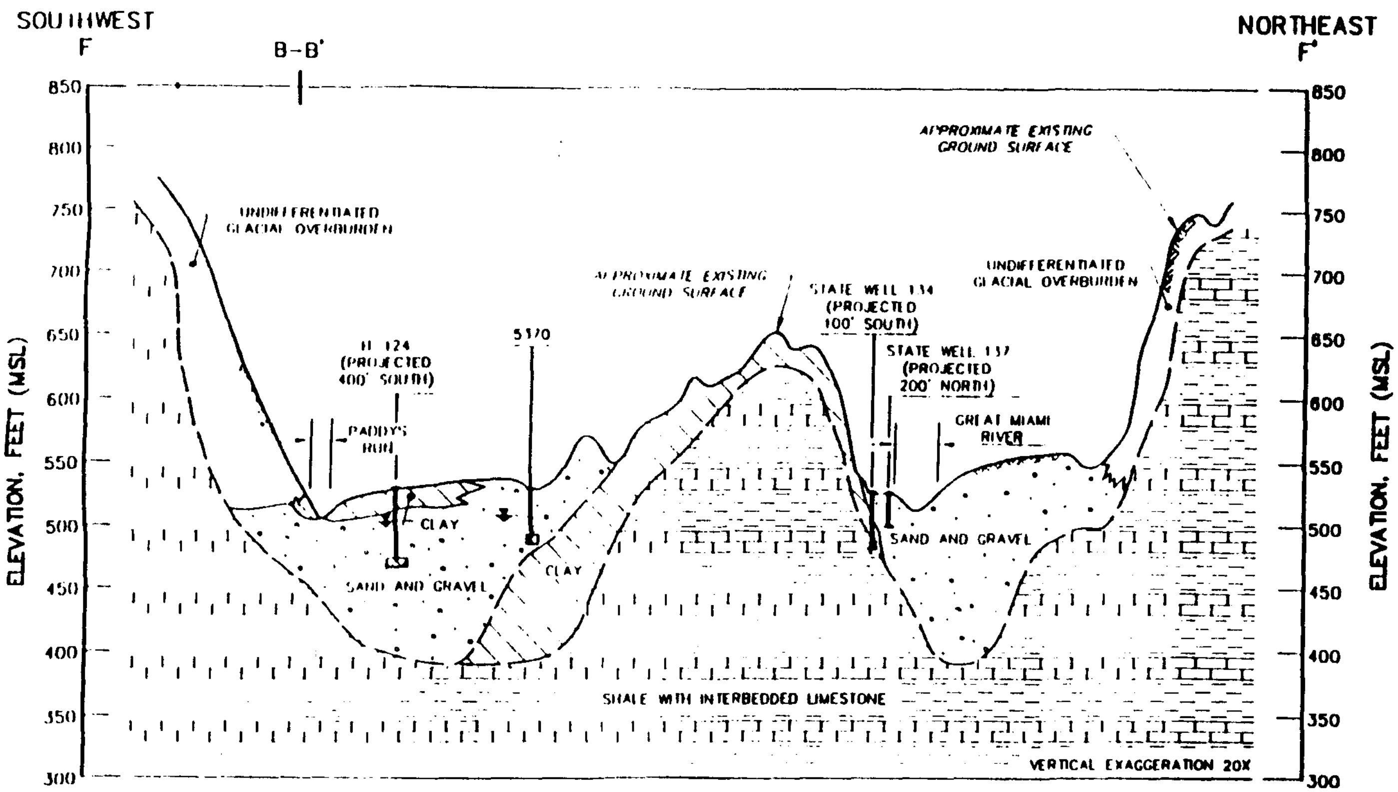
FOR LOCATION OF CROSS SECTION C-C' SEE FIGURE 2-2

REFERENCES:

MODIFIED FROM U.S.G.S. PROFESSIONAL PAPER NO 605-A USING AVAILABLE OHIO STATE WATER WELL RECORDS, SOWC WATER WELL DATA, DAMES & MOORE'S "FEED MATERIALS PRODUCTION CENTER GROUNDWATER STUDY, TASK C REPORT" FOR THE DOE (1985) AND IT (1986) RI/FS BORING LOGS

FIGURE ADAPTED FROM FERNALD LITIGATION DRAWING NO. 301063-B18 PREPARED FOR U.S. DEPARTMENT OF ENERGY BY IT CORPORATION, NOVEMBER 1988

Figure 2-5



CROSS SECTION F–F'

(LOOKING NORTHWEST)

THE BORING LOGS AND RELATED INFORMATION DEPICT SUBSURFACE CONDITIONS ONLY AT THE SPECIFIC LOCATIONS AND DATES INDICATED. SOIL CONDITIONS AND WATER LEVELS AT OTHER LOCATIONS MAY DIFFER FROM CONDITIONS OCCURRING AT THESE BORING LOCATIONS. ALSO THE PASSAGE OF TIME MAY RESULT IN A CHANGE IN THE CONDITIONS AT THESE BORING LOCATIONS.

THE DEPTH AND THICKNESS OF THE SUBSURFACE STRATA INDICATED ON THE SECTIONS WERE GENERALIZED FROM AND INTERPOLATED BETWEEN THE TEST BORINGS. INFORMATION ON ACTUAL SUBSURFACE CONDITIONS EXISTS ONLY AT THE LOCATION OF THE TEST BORINGS AND IT IS POSSIBLE THAT SUBSURFACE CONDITIONS BETWEEN THE TEST BORINGS MAY VARY FROM THOSE INDICATED.

VERTICAL SCALE
0 100 200 FEET

HORIZONTAL SCALE
0 2000 4000 FEET

LEGEND:

WATER LEVELS (MEASURED 3/27/86 THROUGH 4/11/86)

INFERRED CONTACT

OPEN OR SCREENED INTERVAL

NOTE:

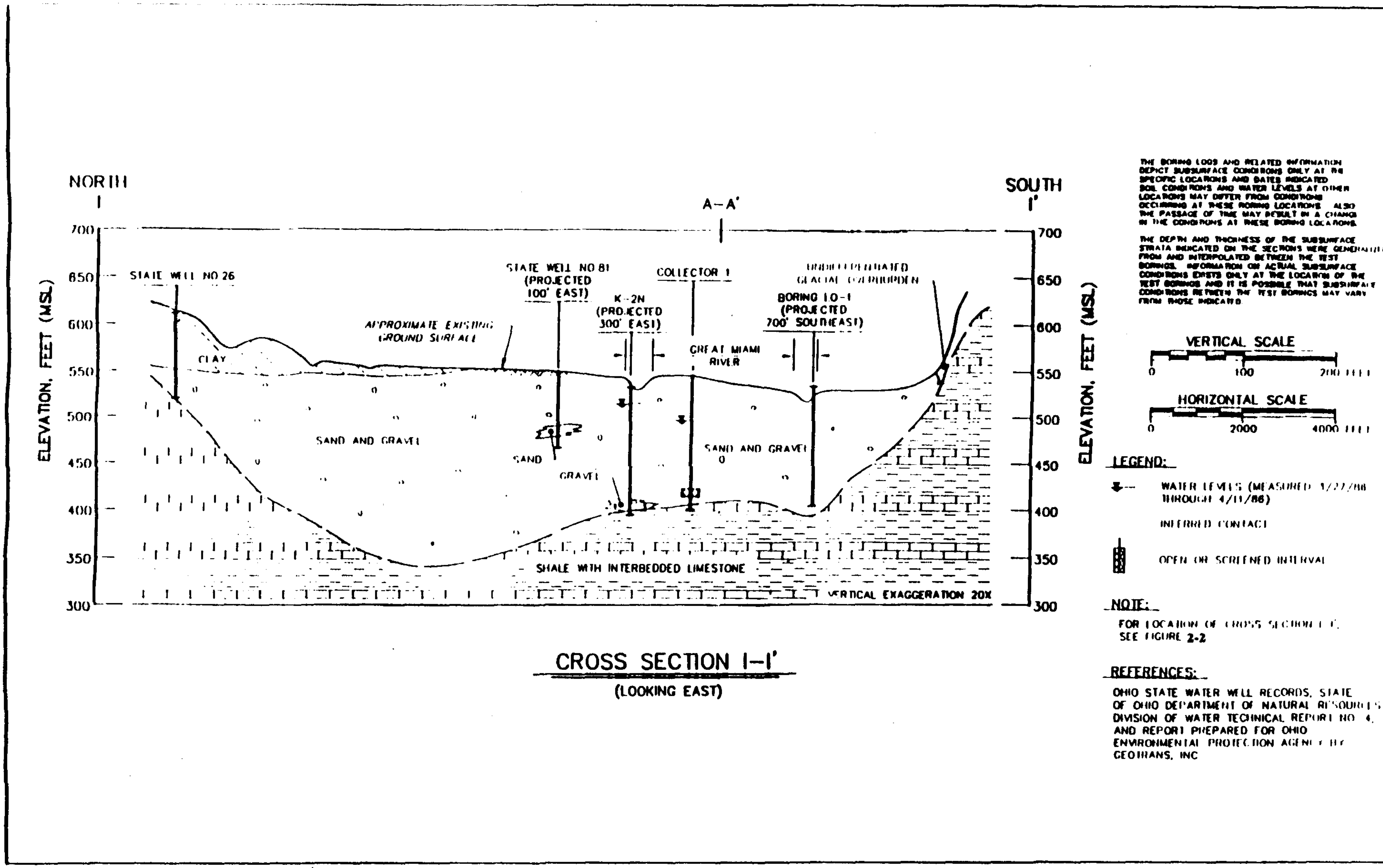
FOR LOCATION OF CROSS SECTION F-F', SEE FIGURE 2-2

REFERENCES:

MODIFIED FROM U.S.G.S. PROFESSIONAL PAPER NO. 605-A USING AVAILABLE OHIO STATE WATER WELL RECORDS, SOWC WATER WELL DATA, DAMES & MOORE'S "FEED MATERIALS PRODUCTION CENTER GROUNDWATER STUDY, TASK C REPORT" FOR THE DOE (1985), AND IT (1986) RI/FS BORING LOGS.

FIGURE ADAPTED FROM FERNALD LITIGATION DRAWING NO. 303063-B21 PREPARED FOR U.S. DEPARTMENT OF ENERGY BY IT CORPORATION, NOVEMBER 1986

Figure 2-6


NORTH
I
SOUTH
I'
A–A'
ELEVATION, FEET (MSL)
700
650
600
550
500
450
400
350
300
STATE WELL NO 26
CLAY
APPROXIMATE EXISTING GROUND SURFACE
SAND AND GRAVEL
STATE WELL NO 81 (PROJECTED 100' EAST)
SAND
GRAVEL
K-2N (PROJECTED 300' EAST)
COLLECTOR 1
GREAT MIAMI RIVER
SAND AND GRAVEL
BORING 10-1 (PROJECTED 700' SOUTHEAST)
UNDIFFERENTIATED GLACIAL OVERBURDEN
SHALE WITH INTERBEDDED LIMESTONE
VERTICAL EXAGGERATION 20X
THE BORING LOGS AND RELATED INFORMATION DEPICT SUBSURFACE CONDITIONS ONLY AT THE SPECIFIC LOCATIONS AND DATES INDICATED. SOIL CONDITIONS AND WATER LEVELS AT OTHER LOCATIONS MAY DIFFER FROM CONDITIONS OCCURRING AT THESE BORING LOCATIONS. ALSO THE PASSAGE OF TIME MAY RESULT IN A CHANGE IN THE CONDITIONS AT THESE BORING LOCATIONS.
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VERTICAL SCALE
0
100
200 FEET
HORIZONTAL SCALE
0
2000
4000 FEET
LEGEND:
WATER LEVELS (MEASURED 1/22/88 THROUGH 4/11/88)
INFERRED CONTACT
OPEN OR SCREENED INTERVAL
NOTE:
FOR LOCATION OF CROSS SECTION I-I', SEE FIGURE 2-2
REFERENCES:
OHIO STATE WATER WELL RECORDS, STATE OF OHIO DEPARTMENT OF NATURAL RESOURCES DIVISION OF WATER TECHNICAL REPORT NO. 4, AND REPORT PREPARED FOR OHIO ENVIRONMENTAL PROTECTION AGENCY BY GEOTRANS, INC
CROSS SECTION I–I'
(LOOKING EAST)

Figure 2-7

section A-A'.

Cross section C-C' (Figure 2-5) shows a perpendicular view of the trending valley. This section also underlies the FEMP and has a fairly constant thickness. The Glacial overburden diminishes in the direction of the Great Miami River due to erosion. The clay interbed is also present in this section.

Cross sections F-F' and I-I' (Figures 2-6 and 2-7) are section in the path of groundwater flow from FEMP. Both show overburden erosion occurring from the Great Miami River. Cross section I-I' ranges in thickness from 150 to 200 feet, and is nearly exclusively composed of sand and gravel with no silt or clay lenses. In section I-I' the Great Miami River often acts as a recharge source and sometimes a discharge area for the aquifer.

3.0 HYDROGEOLOGIC CHARACTERIZATION:

This section discusses the hydrogeologic conditions in the following order: (1) characterization of the hydrogeologic environments in the vicinity of the FEMP, (2) a short description of the Great Miami Aquifer and the perched overburden, (3) observed groundwater elevation and projected groundwater flow, and (4) a general description of the Great Miami River and Paddys Run surface water system interactions with the groundwater systems in the FEMP area.

Two major types of geologic materials in the Femp area consists of Ordovician shale and limestone bedrock, and unconsolidated glacial and fluvial deposits. The New Haven Trough had been excavated from the shale and limestone bedrock, and been filled with the glacial and fluvial deposits. The saturated zones occur in the valley fill deposit and the glacial overburden. 1000-Series monitoring wells are located in the overburden, while 2000- through 4000-Series monitoring wells are placed in the different depths of the Great Miami Aquifer for hydrogeologic characterization. Figure 3-1 depicts the differing depths of the monitoring wells. Numerous monitoring wells are located throughout the FEMP and neighboring areas.

While the sand and gravel deposits of the Great Miami Aquifer represent the classic definition of an aquifer, "a water-saturated unit that will yield water to wells or springs at a sufficient rate so that the wells or springs can serve as practical sources of water supply" (Driscoll 1986), the perched

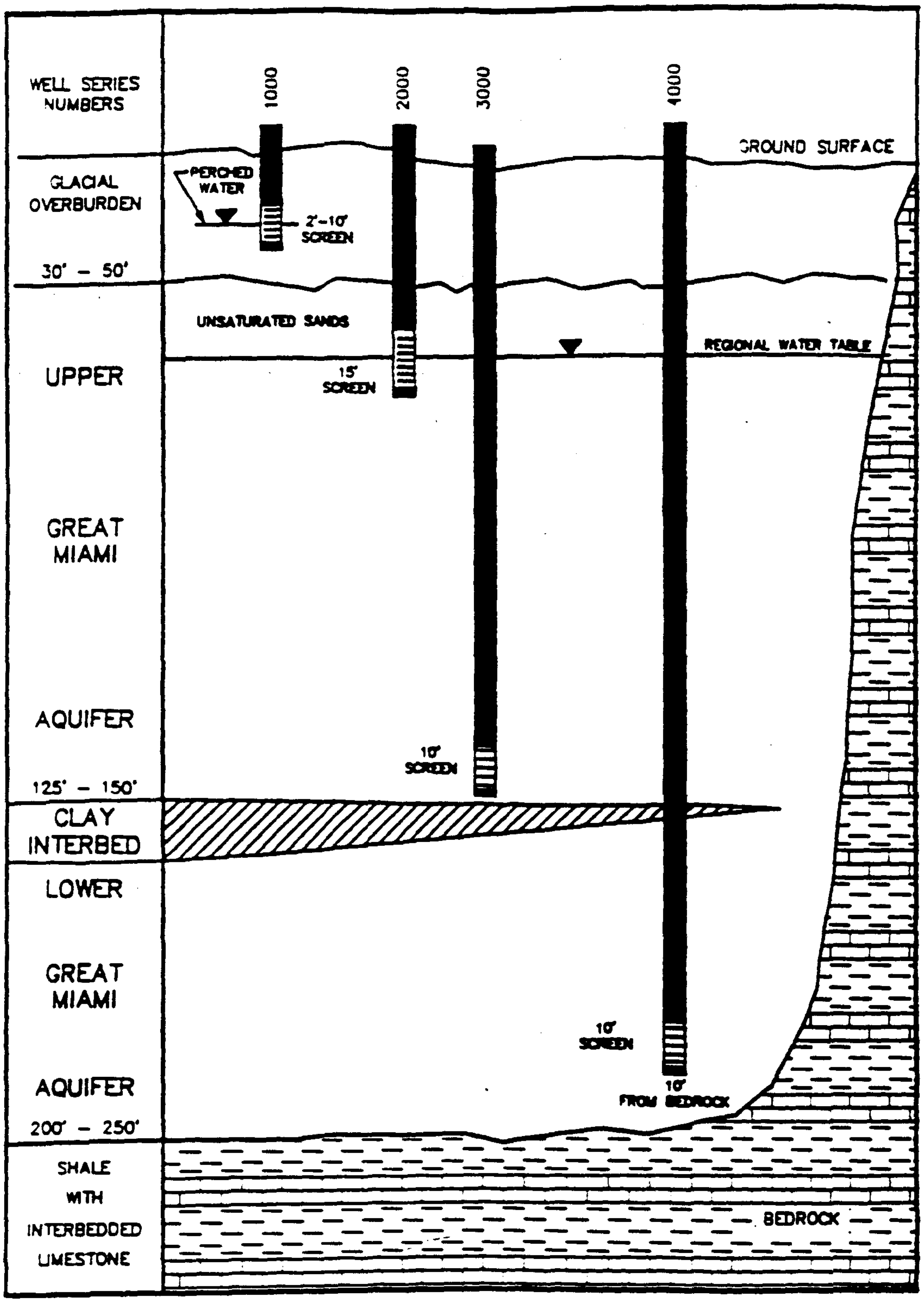


Figure 3-1
Groundwater Monitoring Well Depths

groundwater system of the glacial overburden represents a potential contaminant pathway to the aquifer, streams and springs.

There are three principal recharge sources for the Great Miami Aquifer which are the bedrock, direct precipitation and stream infiltration. The shale of the bedrock is nearly impermeable, water travel through limestone lenses which represents a limited source of recharge for the aquifer. 200,000 gallons per day per linear mile (0.03 gpm/ft) along the valley is approximately the average yearly recharge from the bedrock to the aquifer (Dove 1961).

The dominate recharge source for the aquifer is precipitation within the basin. This generates 570,000 gallons per day per square mile(12in/yr). The recharge through includes glacial overburden, river terraces and flood plain deposits.

Recharge through stream infiltration occurs as a result of pumping water near the Great Miami River. Recharge rates depend on pumping rates, hydraulic gradients, stream bed conditions and water temperature. Paddys Run on the west side of the FEMP and Dry Fork of the White Water River deliver significant amounts of natural seasonal recharge.

3.1 <u>THE GREAT MIAMI AQUIFER</u>:

The Great Miami Aquifer may be divided into five different hydrogeologic environments (Parsons 1993). The hydrogeologic environments characterize areas of the aquifer with their own distinct properties differing from an adjacent area in the aquifer. The differing hydrogeologic environment locations are depicted in Figure 3-2 and are characterized by;

* Type I (Subtypes I-A-I and I-A-2): Sand and gravel aquifer with recharge induced stream infiltration potentially available.
* Type II: Sand and gravel aquifer with no possibility of stream infiltration.
* Type III: Sand and gravel aquifer overlain by clay with stream recharge generally not available.
* Type IV: Buried valley filled with clay, generally large water supplies not available.
* Type V: Shale and limestone bedrock overlain by till, generally large water supplies not available.

The properties of specific yield and transmissivity will be discussed with each description of the hydrogeologic conditions. The transmissivity is a value that denotes the ability for an aquifer to transmit water. The higher the value, the greater the ability to transmit water. The specific yield measures the quantity of water an aquifer will yield from storage when the hydraulic head declines. It is derived from pore space divided by total volume.

The Type I Hydrogeologic environment characterizes the Great Miami Aquifer to the south and east of the FEMP facility, and also in the valley of Paddys Run west and south of the FEMP former production area. Type I-A-I aquifer ranges in thickness

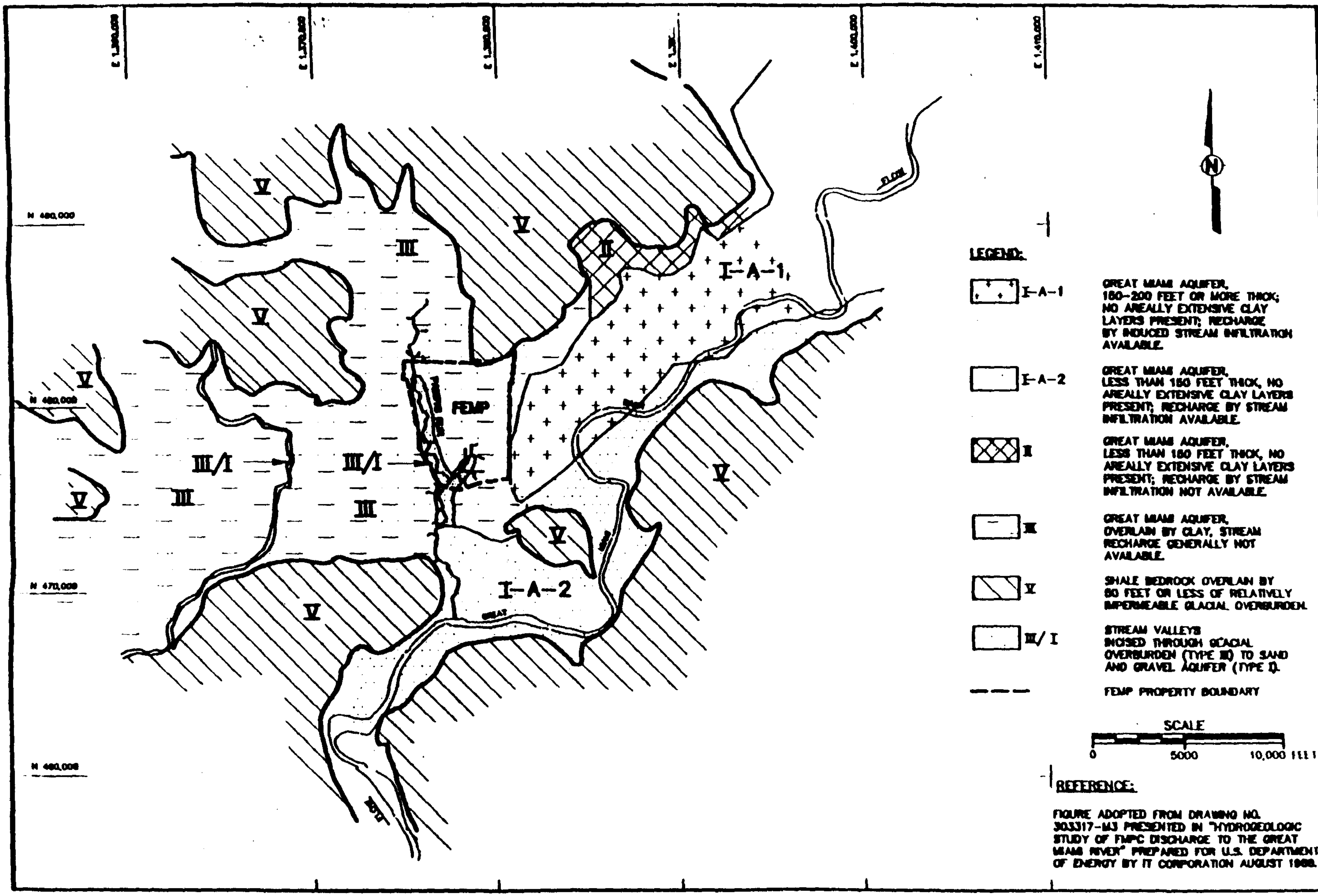


Figure 3-2
Location of Hydrogeologic Environments

from 150 to 250 feet, while the Type I-A-2 aquifer is less than 150 feet thick. Stream infiltration is possible in areas proximal to local streams such as Paddys Run, since sediments crop out at the surface. Each are under lain by bedrock. The lithology primarily consists of well sorted sand and gravel, the appearance of scattered lenses of clay and fine grained material are present. The lenses are not sufficient or areal extent to act as semiconfining layers or significantly effect the groundwater movement. The aquifers transmissivity usually ranges from 40,000 to 67,000 square feet per day (ft^2/day),with a specific yield about .2. In these aquifers individual pumping wells have yielded 3000 gpm.

The Type II hydrogeologic environment has less than 150 feet of sand and gravel, with no apparent clay lenses. The aquifer generally has no large water supplies available, and has a specific yield of about .2. Areas of Type II environment are of limited areal extent. This hydrogeologic environment is generally located adjacent to the bedrock walls.

Rich in clay glacial overburden overlying the Great Miami Aquifer characterizes the Type III hydrogeologic environment. The aquifer is divided into an upper and lower part by a clay interbed about 10 to 20 feet thick, occurring approximately 140 feet below the surface within the FEMP area. The lower aquifer is depicted as a semiconfined or leaky aquifer. The specific yield of the lower aquifer is estimated at .001 with a transmissivity ranging from 4700 to 40,000 ft^2/day. Small streams occur in areas overlain by glacial overburden with stream infiltration generally not occurring. Though areas in which the streams have eroded some of the glacial overburden, recharge by stream infiltration is the result. The Type III/I symbol appears on Figure 3-2 depicting these areas.

The Type IV hydrogeologic environment does not occur in the FEMP area or vicinity.

The Type V hydrogeologic environment refers to all the area outside the buried valley of the Great Miami Aquifer. The shale and interbedded limestone bedrock are overlain by 50 feet or less of glacial overburden. This material does not transmit large amounts of ground water. Sand and gravel lenses are distributed unevenly through out the glacial overburden and have yielded up to 50 gpm.

3.2 GROUNDWATER SYSTEM IN THE GLACIAL OVERBURDEN

Groundwater occurs in the glacial overburden. Slug tests were performed in selected 1000-Series wells to define the hydraulic conductivity of the glacial overburden in and around the storage waste area and the flyash pile areas. Table 3-1 contains the results of the slug tests and which wells were selected. The local variation in the till reflects in the variability in the values obtained.

Dense fine grained glacial till and glacial lacustrine deposits of silt and clay act as aquitard in most areas. Layers of relatively high conductivity form from small scale fluvial and

TABLE 3-1

SUMMARY
HYDRAULIC CONDUCTIVITY TESTING

Monitoring Well No.	Subsurface Soil Type	Hydraulic Conductivity (cm/s)	Hydraulic Conductivity (ft/day)
1008	Clay, Trace Gravel	1.3×10^{-4}	0.37
1012	Clay w/Gravel, Shale Bedrock	1.6×10^{-3}	4.53
1018	Sand, Silt, Clay	5.7×10^{-4}	1.61
1025	Clay, Trace Gravel	2.5×10^{-6}	0.01
1034	Clay, Fine Sand, Some Silt and Gravel	2.5×10^{-5}	0.07
1035	Clay, Some Silt	2.5×10^{-5}	0.07
1041	Clay, Some Silt	1.1×10^{-4}	0.31
1046	Clay, Silt, Sand	6.8×10^{-5}	0.19
1048	Clay, Silt, Sand, Gravel	1.6×10^{-4}	0.45
1065	Silt, Some Clay, Some Sand	2.2×10^{-5}	0.06
1079	Clay, Some Sand, Some Gravel	1.8×10^{-5}	0.05

beach deposits within the till. The hydrogeologic characteristics vary with specific location and the season. In the FEMP area, depth to perched groundwater in the overburden ranged from 1 to 15 feet. A fluctuation of 10 feet in a single location may occur seasonally with this water table. The highest levels are during the early spring and lowest in the late fall.

In the four glacial overburden materials present in the FEMP area and vicinity have the following hydrogeologic characteristics.

* Loess: Deposits consist of silt and small amounts of clay. With a porosity of 40 to 50 percent these deposits are moderately cohesive. The reported hydraulic conductivity for the loess is 0.028 ft/day to 2.8 ft/day (1.0×10^{-5} cm/s to 1.0×10^{-2} cm/s), without secondary permeability. Due to fracturing, animal burrows and root tubes, near surface deposits of loess have an enhanced secondary permeability. Secondary permeability that greatly exceeds the unenhanced permeability are the results of these features.
* Lacustrine Deposits: Consists of silt and clay with interbedded sands and gravel. The interbedded sands and gravel deposits may form aquifers, but are limited in yield and extent.
* Till: No attempt has been made to differentiate the till types or determine if individual till types exist. The till consists of a heterogenous mixture of silt, clay, sand,

gravel and boulder sized materials. Overall the till in the FEMP area and vicinity is too fine grained to be a permeable hydrogeologic unit. The till acts as an aquitard in the FEMP area, although infiltration does occur in the weathered till though most water is lost to evapotranspiration. Also some water discharges laterally to seeps or drainage.

* Glaciofluvial Deposits: Most of the large productive aquifers are found in the glaciofluvial outwash. These deposits occur as extensive blanket valley fill deposits, and consist of well sorted sand and gravel. In the FEMP area, these deposits may have interbedded tills acting as aquitards and are confined by surface layers of till or glaciolacustrine silts and clays.

Movement of the groundwater in the FEMP area, generally is toward Paddys Run and the storm sewer outfall ditch. The groundwater movement is generally discontinuous with different areas affected by different influences. Due to variation in recharge, the flow patterns vary seasonally. Drain tile installed by the previous owner of the area also influence the flow.

3.3 ELEVATION AND FLOW OF GROUNDWATER

Figure 3-3 depicts the generalized groundwater movement of the Great Miami Aquifer. It shows groundwater entering the FEMP area from three separate directions. Flow from the Ross section in the northeast characterizes movement toward the southwest. The

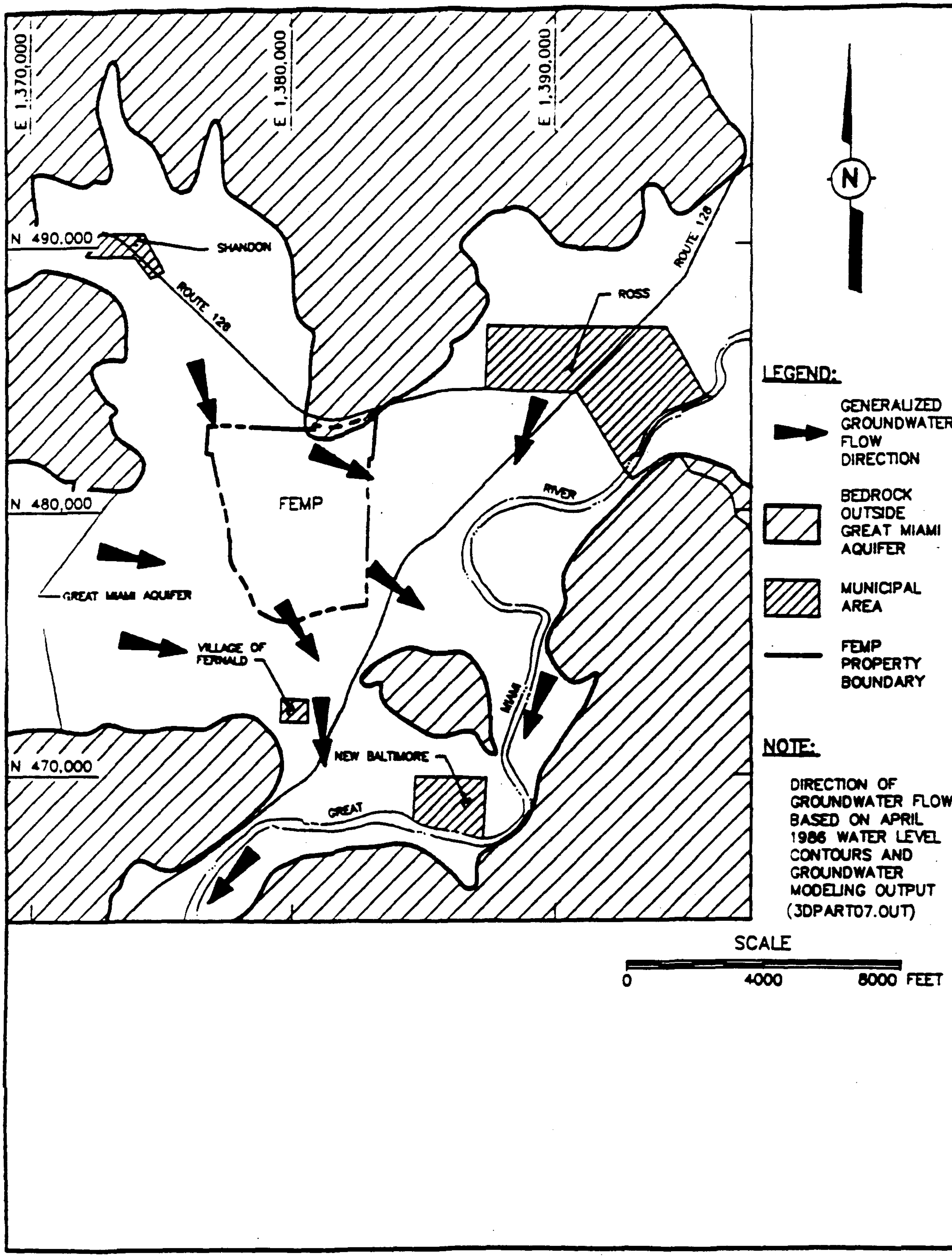


Figure 3-3
Generalized Groundwater Flow Direction

Shandon Tributary, in the northwest represents the second source of groundwater, which the majority of flows under the waste storage area and the former production area and exits along the eastern border of the FEMP to discharge in the Great Miami River. Pumping of collector wells strongly influences this flow. Recharge from the Dry Fork and Whitewater River, which is two miles east of the FEMP, represents the final source of groundwater from the west. The flow enters in an eastward bound path and soon turns southward under the southern part of the FEMP, and flows to the Great Miami River in the glaciofluvial deposit under the southern part of Paddys Run. Local and short term variations do occur to the flow.

From more comprehensive groundwater elevation surveys in August 1982, April 1986 and May 1988 regional groundwater maps were constructed and displayed in Figures 3-4, 3-5 and 3-6. The following conclusions arise from analysis of these maps.

* From the north, west and northwest groundwater enters the FEMP and exits toward the Great Miami River Valley to the south and toward the Great Miami River and Southwestern Ohio Water Company (SOWC) production wells to the east.
* A pronounced cone of depression East of the FEMP, near the large bend in the Great Miami River is caused by large withdrawal from SOWC pumping wells. Groundwater divide trending northwest to southeast across the south central portion of the FEMP, is the result of an induced eastward flow in the northern and central portion of FEMP toward

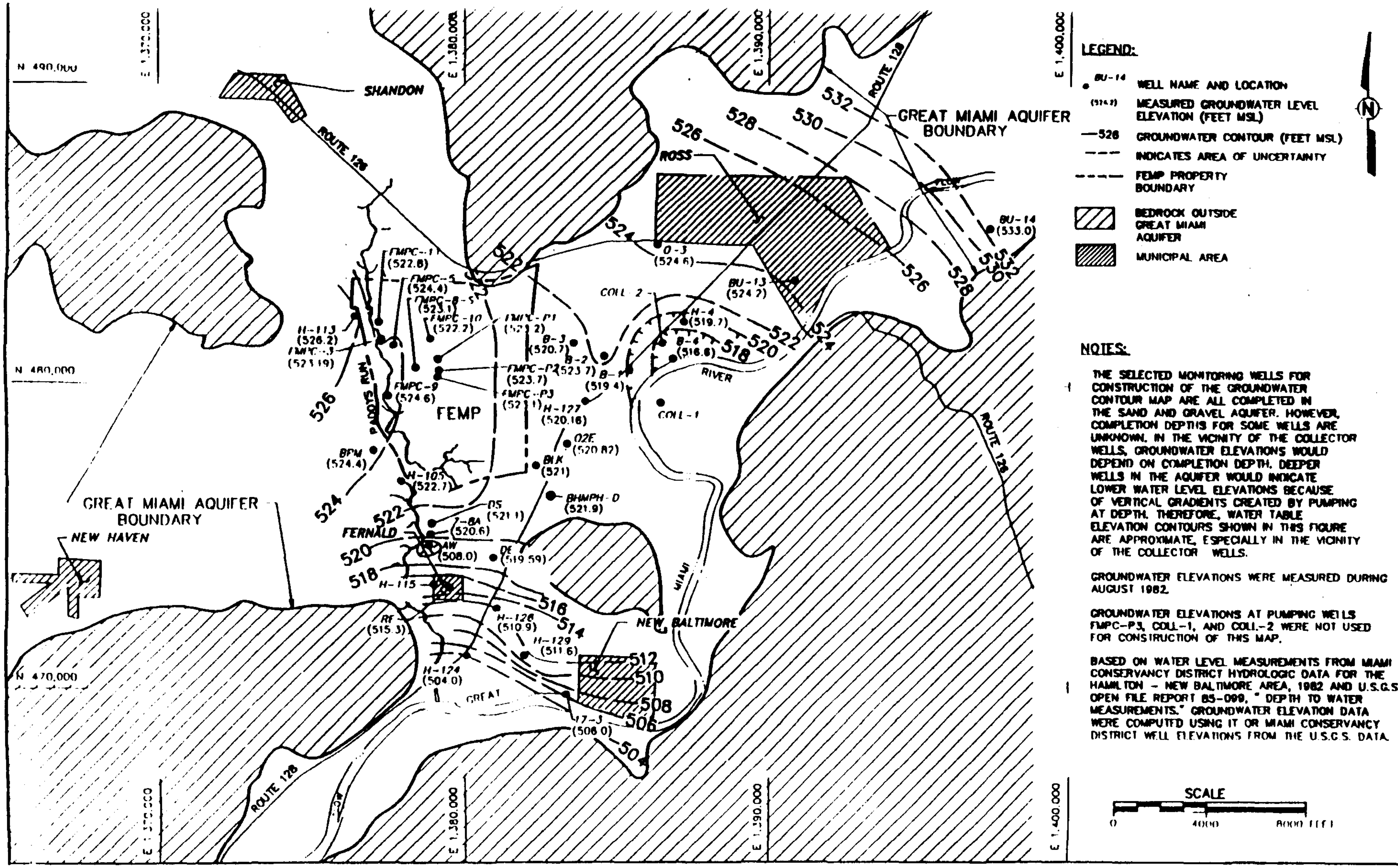


Figure 3-4
Regional Groundwater Maps for August 1982

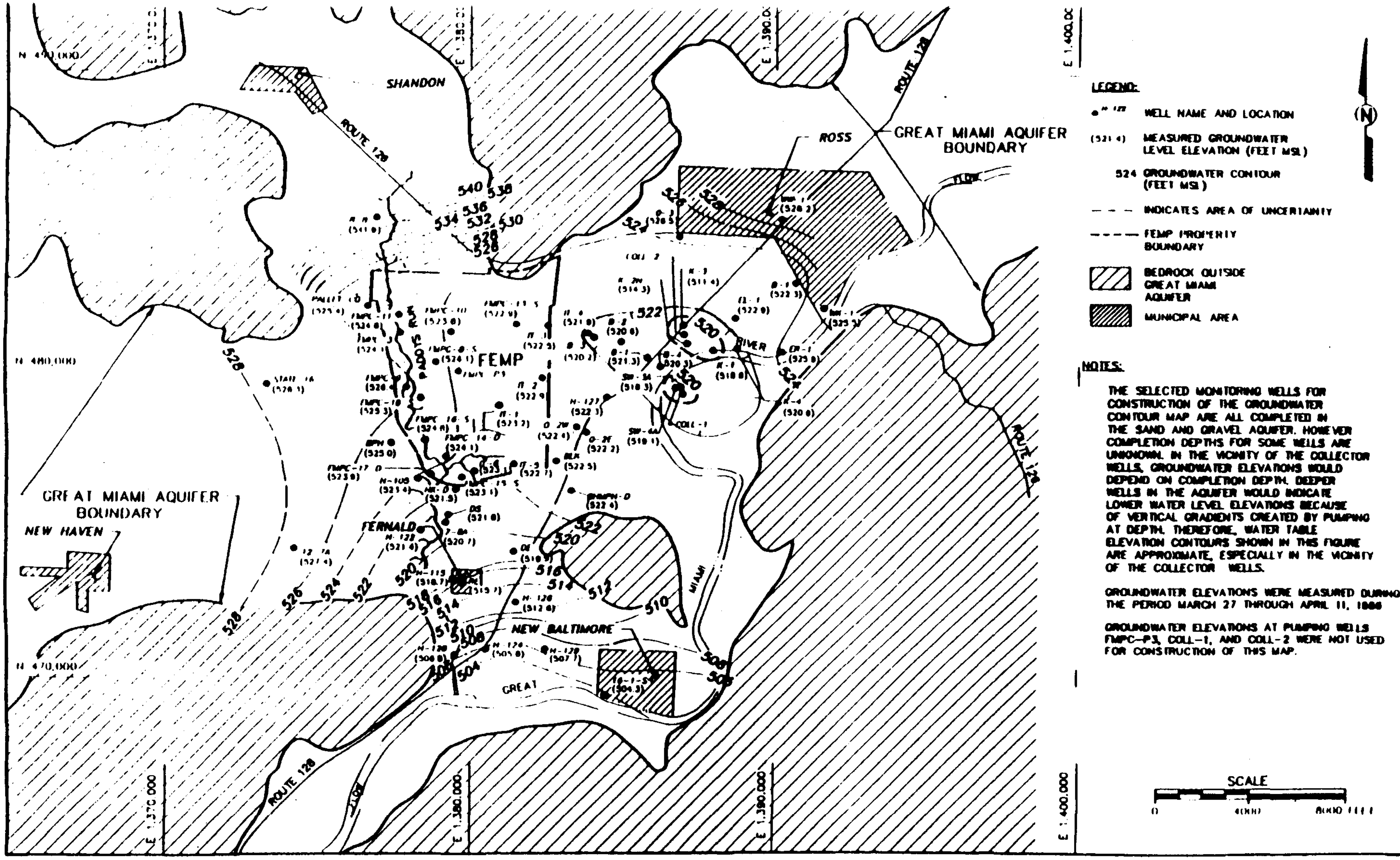


Figure 3-5
Regional Groundwater Maps for April 1986

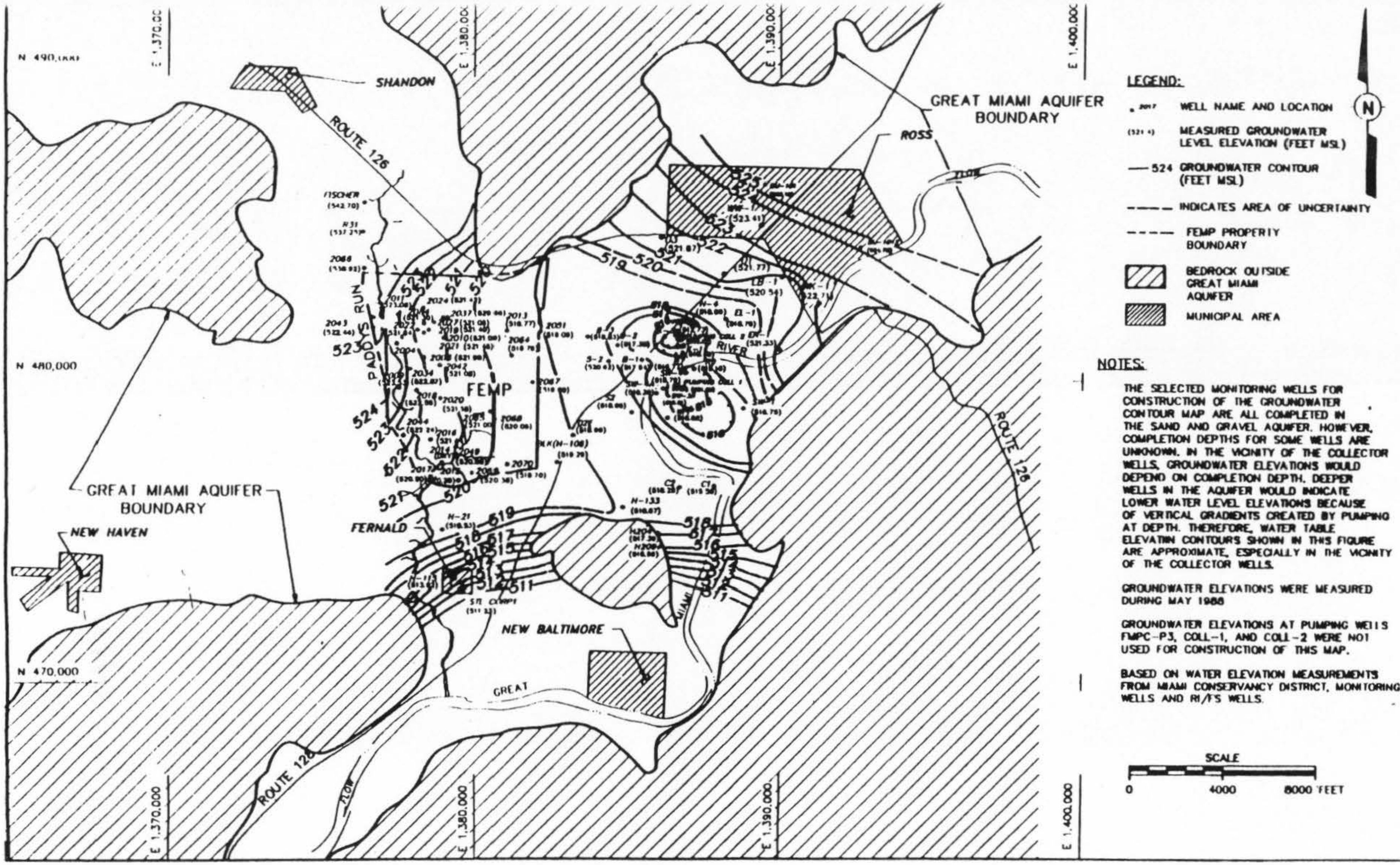


Figure 3-6
Regional Groundwater Maps for May 1988

portion of the FEMP, is the result of an induced eastward flow in the northern and central portion of FEMP toward this cone of depression.

* Along the western boundary south of the FEMP the groundwater flow is influenced by Paddys Run. During low recharge the groundwater flows southeastward. In contrast stream infiltration occurs during seasonally high flows in Paddys Run and creates a groundwater mound and strong southward gradients. As result, northward flow actually occurs in the northern FEMP.
* The surrounding bedrock also influences the groundwater flow direction. Groundwater flow due south toward the Great Miami River is caused from a combination of eastern and western bedrock highs. As expected the groundwater gradient steepens in the narrow bedrock channel.
* As discussed in section 3-4, short term fluctuations in groundwater elevations occur due to surface water and groundwater interaction.

A cyclic trend in water level readings is observed in Figure 3-7, a hydrograph of Monitoring Well 02E. The hydrograph representative of trends in other FEMP monitoring wells which shows 4 to 6 feet general fluctuation in yearly water levels. It also shows generally high water levels in spring and early summer, and low water levels in fall and early winter. This is seemingly the typical pattern of water table fluctuation in southern Ohio, with an average recharge period of 4 to 5 months

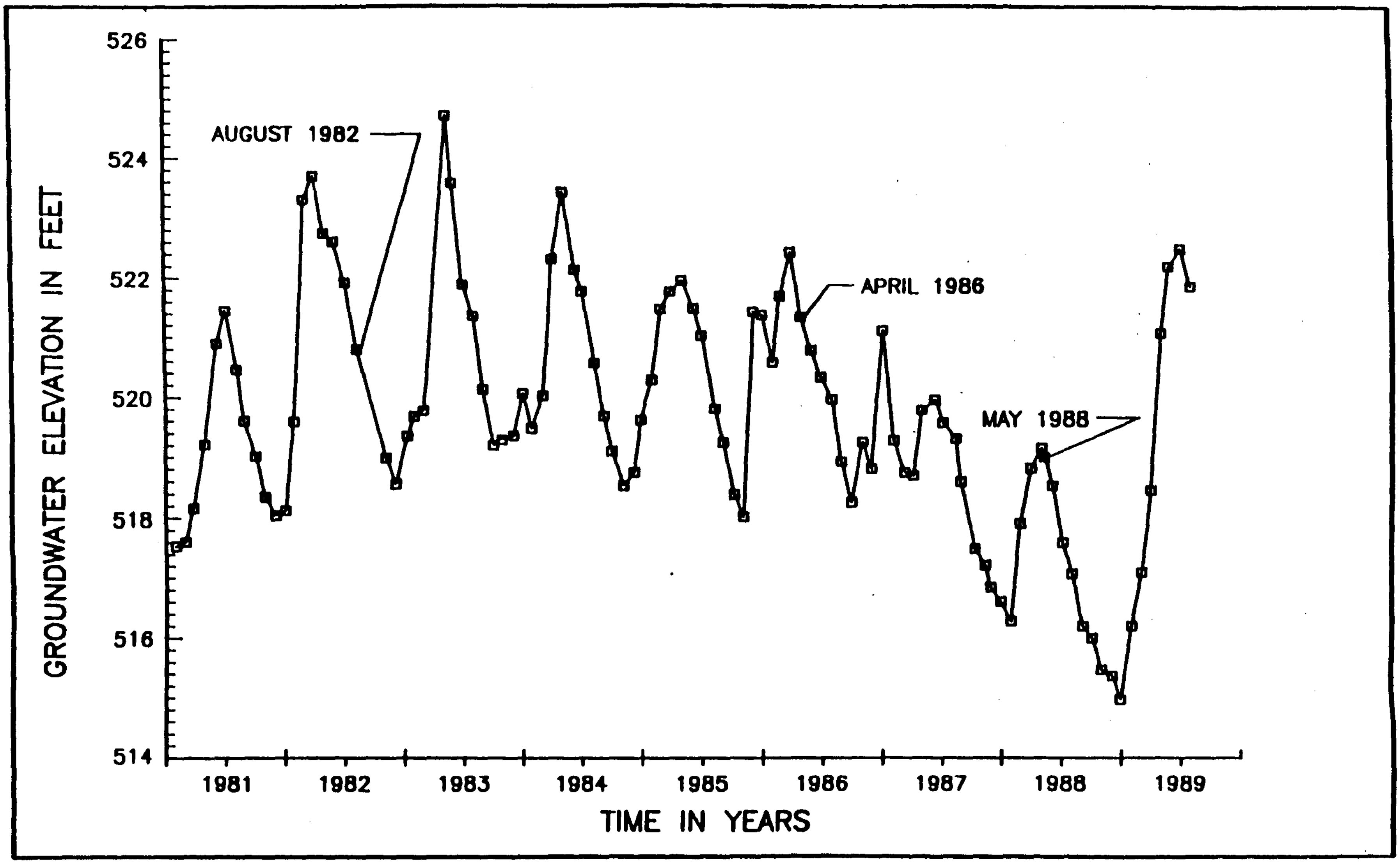


Figure 3-7
Hydrograph of Monitoring Well 02E
January 1981 to December 1989

1988.

3.4 <u>SURFACE WATER AND GROUNDWATER INTERACTION</u>

Both the Great Miami River and Paddys Run interact with the groundwater, having eroded away glacial overburden allowing this to occur. This modification is important in relation to a increase use of the aquifer for purposes of water supplies and contaminant transport.

With eroded glacial overburden and partial penetration of the water table with the Great Miami River, a portion of its flow originates from surface water while a portion from groundwater. Under natural conditions, groundwater generally discharges into the river, but with collector wells pumping near the river, recharge to the aquifer by stream infiltration results. The stream infiltration varies with respect to the season, location, river stage, hydraulic head, streambed characteristics and water temperatures.

During the summer of 1956 near Ross (Dove 1961) and in Fairfield Township in the summer of 1962 (Spieker 1968a), the riverbed infiltration rate was investigated. Infiltration rates of 240,000 and 492,000 gallons per day per acre (3,200 and 6,600 in/yr) of streambed were calculated. Each test was conducted in similar terrains, under low stream flow conditions , and with water temperatures approximately 80°F. Due to high degree of induced infiltration that occurs upstream, the FEMP effluent discharge did not have a quantifiable effect on groundwater quality.

Paddys Run erosion of glacial overburden allows it to interact with the Great Miami Aquifer, affecting groundwater flow and discharge. The interaction is observed as Type III/I in Figure 3-2. The elevation of the water table is close to or above the elevation of the stream bottom south of the FEMP. In the vicinity of FEMP, Paddys Run is above the water table and recharges water to the aquifer. Generally it is dry except during runoff periods following snow melt or rainfall. Just north of the position of the silos, refer to Figure 1-2, there is relatively little recharge of the aquifer due to the presence of clayey till.

Regional aquifer hydrographs and Paddys Run hydrograph show a high degree of correlation as seen in Figures 3-8 and 3-9. The correlation indicates the hydrologic connection between the stream and the regional aquifer.

A groundwater mound occurs centered on Monitoring Wells 2108 and 2009, and under extremely wet conditions from Monitoring Well 2004 to Monitoring Well 2107 from increases in runoff from Paddys Run. The mound is most pronounced during periods of high precipitation, where the groundwater flow is then effected. There is only a slight influence during dry months of a normal year.

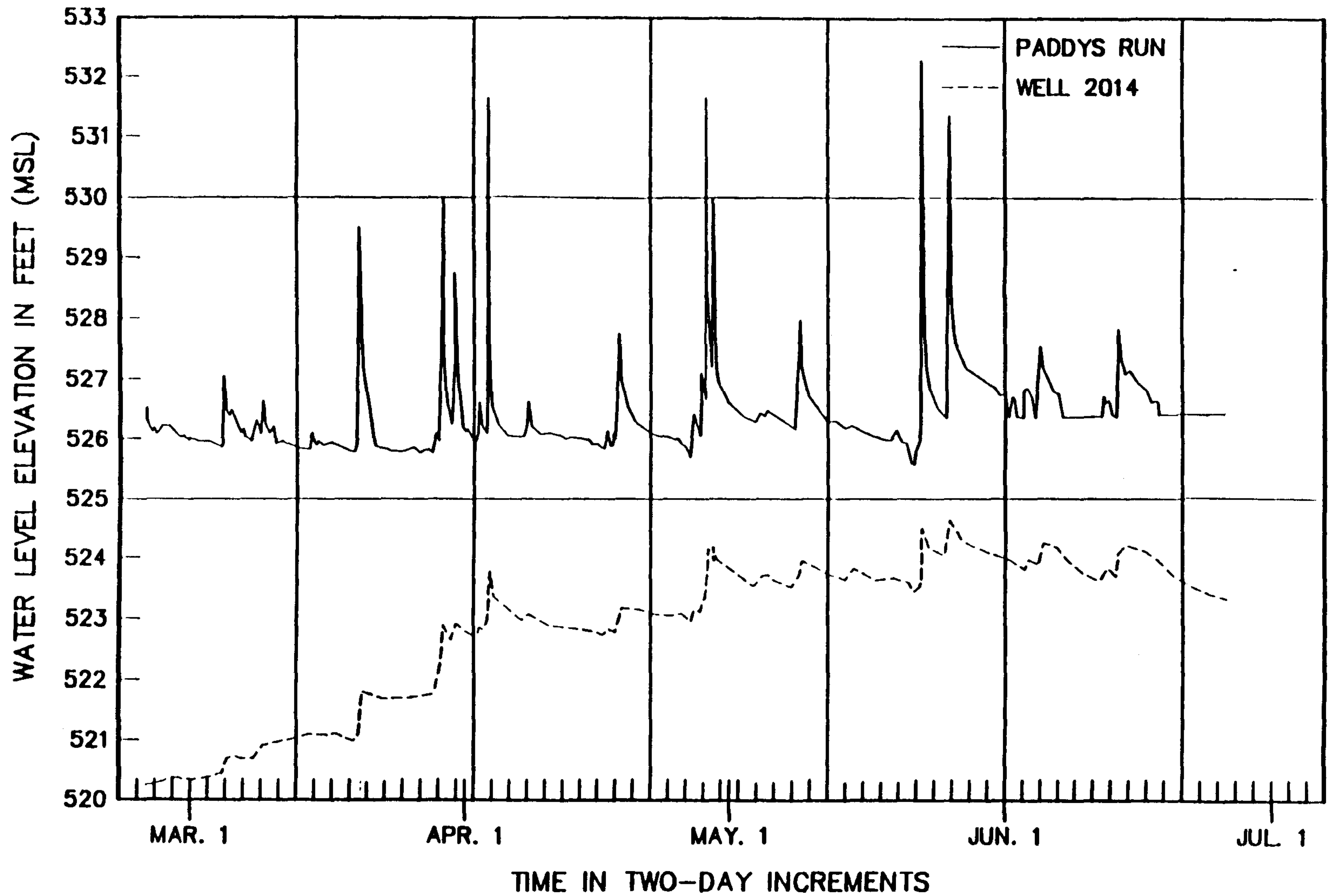


Figure 3-8
Hydrograph of the Great Miami Aquifer and
Paddys Run at Well Location 14
February 24, 1989 to June 26, 1989

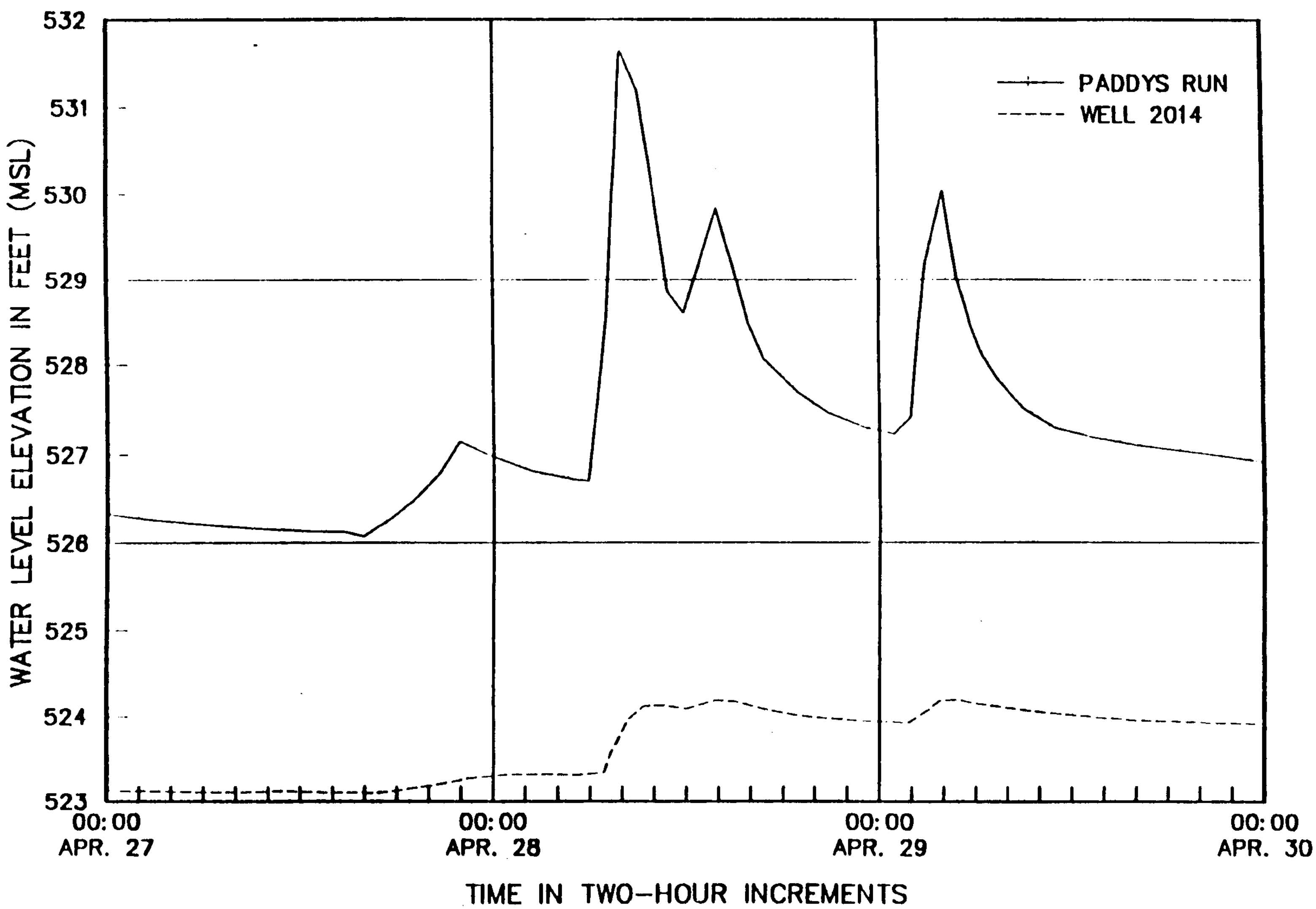


FIGURE 3-9
Hydrograph of the Great Miami Aquifer and
Paddys Run at Well Location 14
April 27, 1989 to April 30, 1989

4.0 URANIUM GROUNDWATER CONCENTRATION:

Leakage from storage pits have caused level of uranium concentrations in the groundwater to rise from the background levels of 0.068 to 2.03 pCi/L. Of the numerous private wells in the area, four have shown readings averaging above the 13.5 pCi/L proposed United States Environmental Protection Agency (USEPA) standard. Figure 4-1 shows the locations of several private wells in the area, while Figure 4-2 depicts the average yearly uranium concentrations in the private wells from 1988 to 1992.

Comprehensive sampling to try to characterize the plume has taken place, with 844 analyses for total uranium at 216 on and off site monitoring wells. Concentrations in 85 of the samples were above the proposed USEPA guidelines of 13.5 pCi/L. The sample was drawn from beneath the production area in the glacial overburden, from Monitoring Well 1085. The identification of the South Groundwater Contamination Plume was achieved through groundwater sampling for the past several years. Figure 4-3 characterizes the area of uranium contamination in the upper sand and gravel aquifer. Pumping tests were performed to best determine removal action as discussed in section 5.0.

Figure 4-1: Locations of Private Well Monitoring

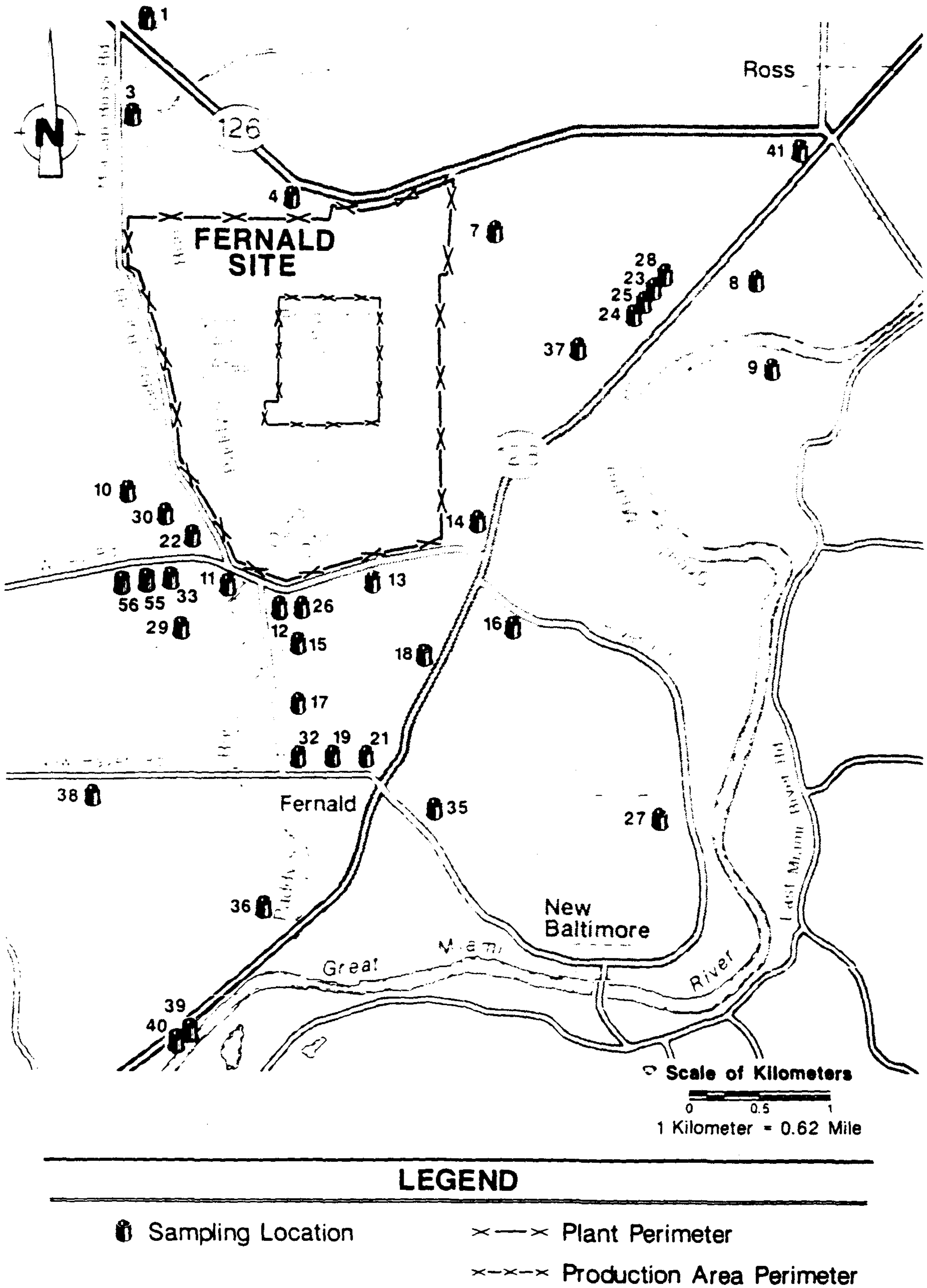


Figure 4-2: Average Yearly Uranium Concentrations in Private Wells, 1988 to 1992

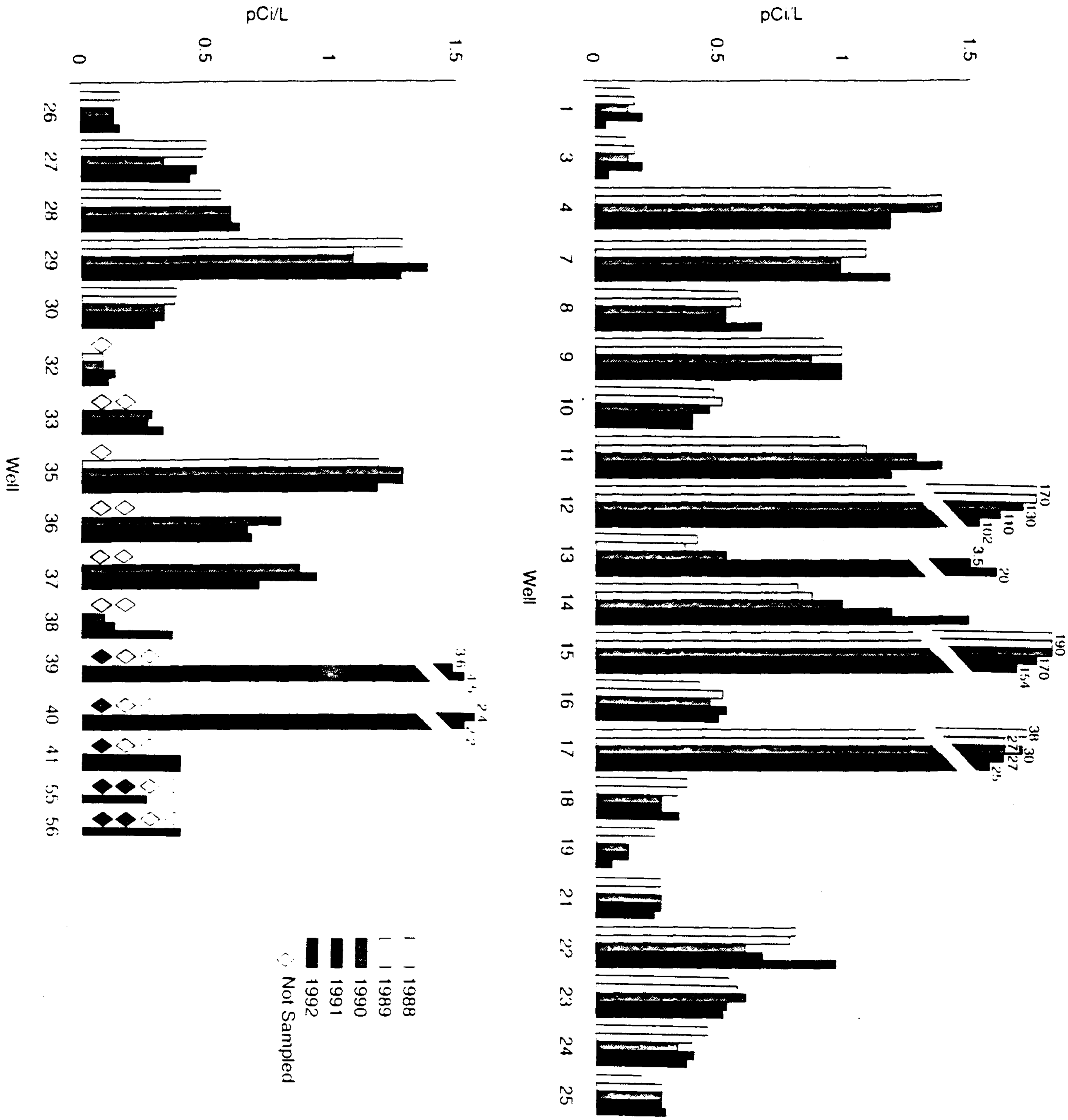
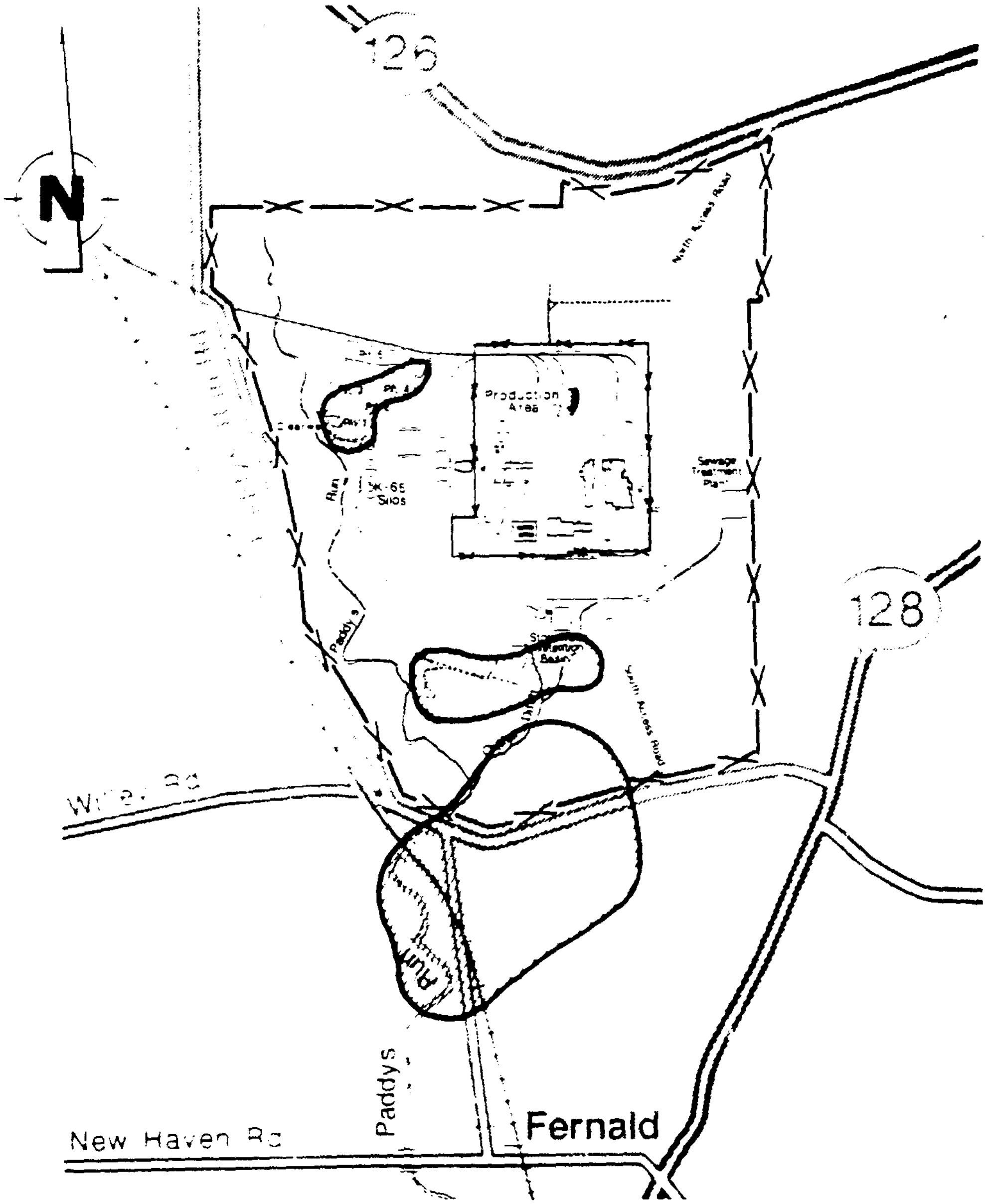


Figure 4-3: South Groundwater Contamination Plume



Scale of Kilometers

0 1.0 2.0

1 Kilometer = 0.62 Mile

LEGEND

Area of Total Uranium Exceeding 20 parts per billion	×—× Plant Perimeter
	×–×–× Production Area Perimeter

5.0 AQUIFER TEST

Determination of hydraulic parameters in the Great Miami Aquifer involved an aquifer test with Recovery Well 4 (RW-4) as a pumping well and eight observation wells. Locations for the wells are depicted in Figure 5-1. A maximum discharge rate of 600 gpm was established for RW-4, which has a 16 inch inside diameter. A description of the components for the pumping tests are listed in Table 5-1. Water was discharged away from the site with an 8 inch HDPE temporary pipeline running approximately 500 feet north to a force main, and to the Great Miami River. The test pump was positioned 7 feet above the base of the screen in RW-4. The discharge flowed through a 90 degree elbow at the top of the well casing. On top of the elbow is a 1/2 inch combination air vent and sampling port. Located downstream the elbow was a check valve, followed by a butterfly valve for isolation, the primary flow detector, agate valve and the secondary flow meter.

The eight observation wells consisting of piezometers have depths varying from 110 to 150 feet. The pre-test water table occurred at a depth of 70 feet below the ground surface for RW-4. Table 5-2 identifies the wells, distance from RW-4, method of observation and their depths. The pumping test will be interpreted using Theis, Cooper-Jacob, Jacob Distance-Drawdown and the Neuman Methods. Theis and the Cooper-Jacob Methods are used to help obtain initial parameter estimations for the Neuman Method.

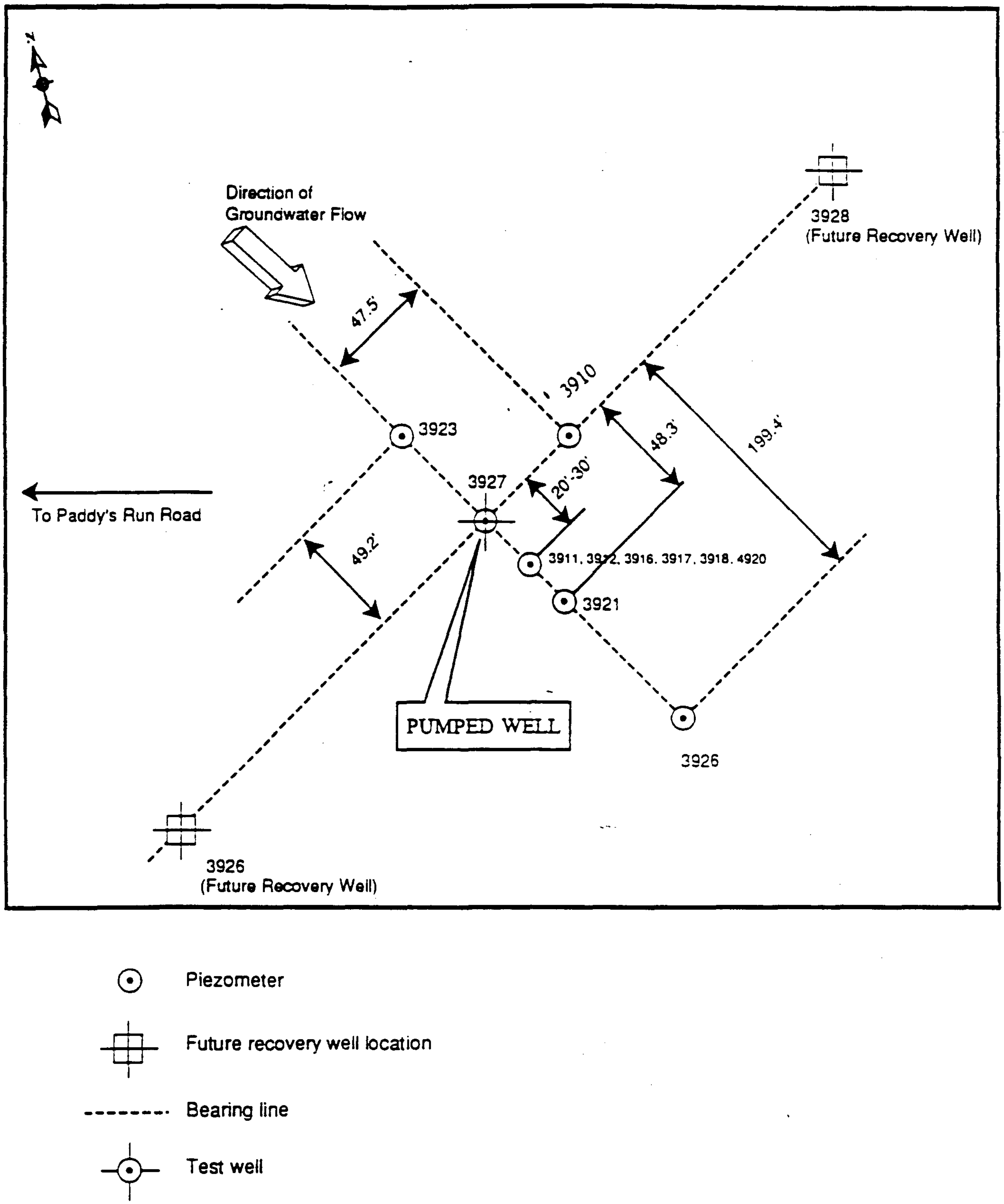


Figure 5-1
Location of Observation Wells

Table 5-1 Pumping Test Components

Components	Description
Test Pump	Worthington Model 10H7S, 600-900 gpm submersible pump with a 60 horsepower, 460 volt, 3-phase motor
Primary Flow Meter/Totalizer	YOKOGAWA - Johnson Model YF115-ALSAIA-S3S3*C/FMF 6-inch Voltex flow meter
Secondary Flow Meter/Totalizer	McMROMETER, mechanical flow meter with totalizer
Diesel Generator	300 KW
Throttle Valve	8-inch gate manuel valve

Table 5-2 Pumping Test Monitoring Well Information

Well #	Depth	Distance to RW-4 (ft)	Method of Observation
3910	110	47.5	Data Logger
3911	110	19.9	Data Logger
3916	130	29.2	Data Logger
3917	140	25.1	Data Logger
3918	150	24.3	Data Logger
3921	110	48.3	Data Logger
3922	110	199.4	Data Logger
3923	110	49.2	Data Logger

5.1 Jacob Distance-Drawdown Method

The Jacob Distance-Drawdown Method requires one pumping well and a minimum of three observation wells located at different radial distances. From the pumped well, measured drawdowns are plotted as a function of distance, in theory produce a straight line semilogarithmic plot. The slope of the line is then used to compute the parameters of interest.

The Theis equation on which the Jacob method is based is valid for confined aquifers and fully penetrating wells. This method can be used for unconfined aquifers if the aquifer is relatively permeable and dewatering of the aquifer is not significant (Heath 1987). The Great Miami Aquifer is known to be a prolific aquifer. The saturated thickness of the aquifer in this area is 96 feet. Drawdown 20 feet from the pumping well is less than 1.6 feet, and 0.9 feet of drawdown occurs 200 feet from the test well. Dewatering was corrected by the use of the following equation.

$s' = s - (s^2/2D)$

The corrected drawdown data shows a less than 1 percent change in the observed drawdown occurs due to dewatering (Papadopulos and Cooper 1967). The effects of partial penetration does effect the test, for wells close than 190 feet. However the effects of partial penetration decrease with distance away from the pumping well. Figures 5-1, 5-2 and 5-3 shows the distance drawdown plots for each time period.

Drawdown from 4 separate observation wells was collected

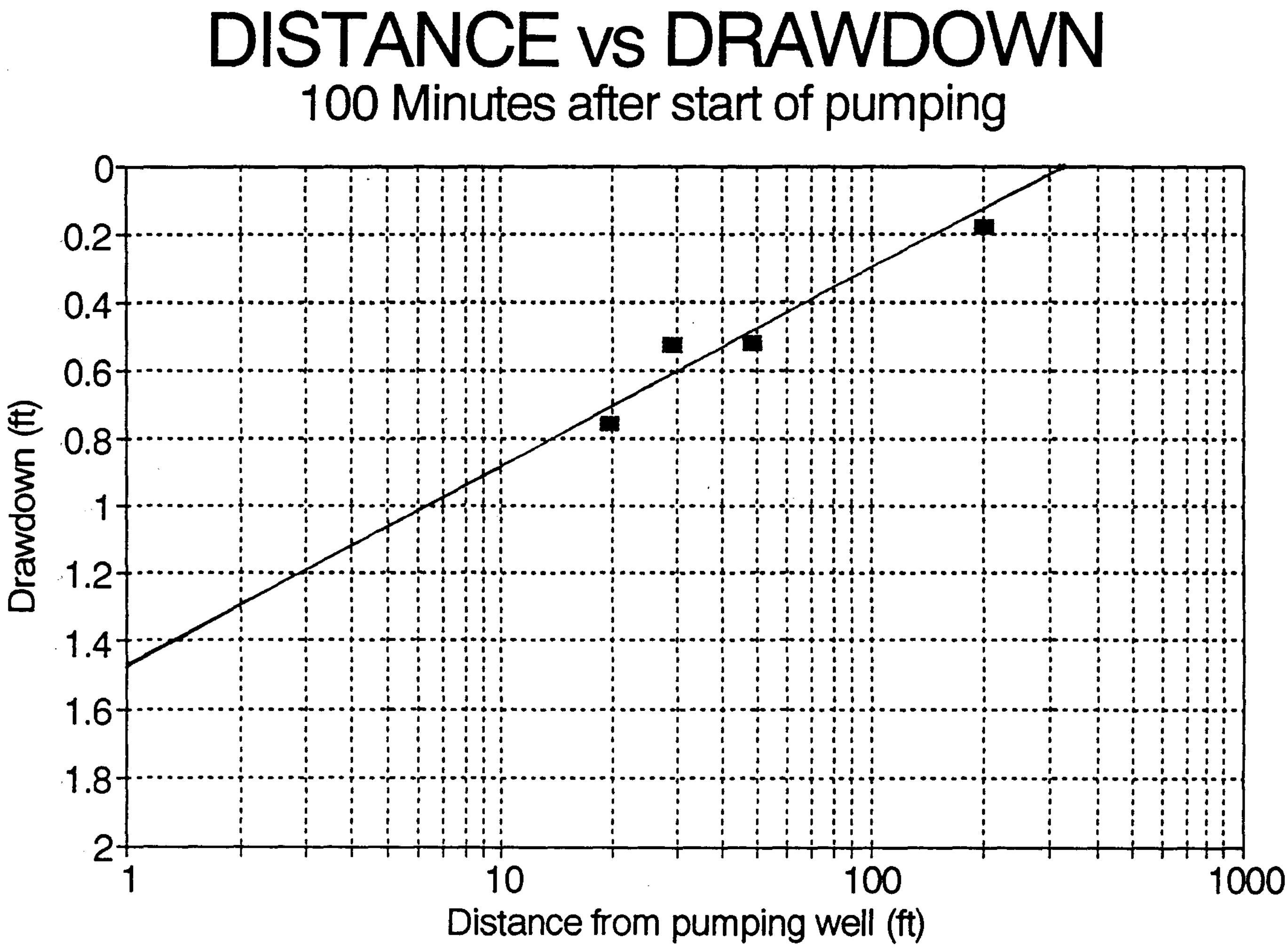


Figure 5-2
Jacob Distance-Drawdown Method for 100 Minutes

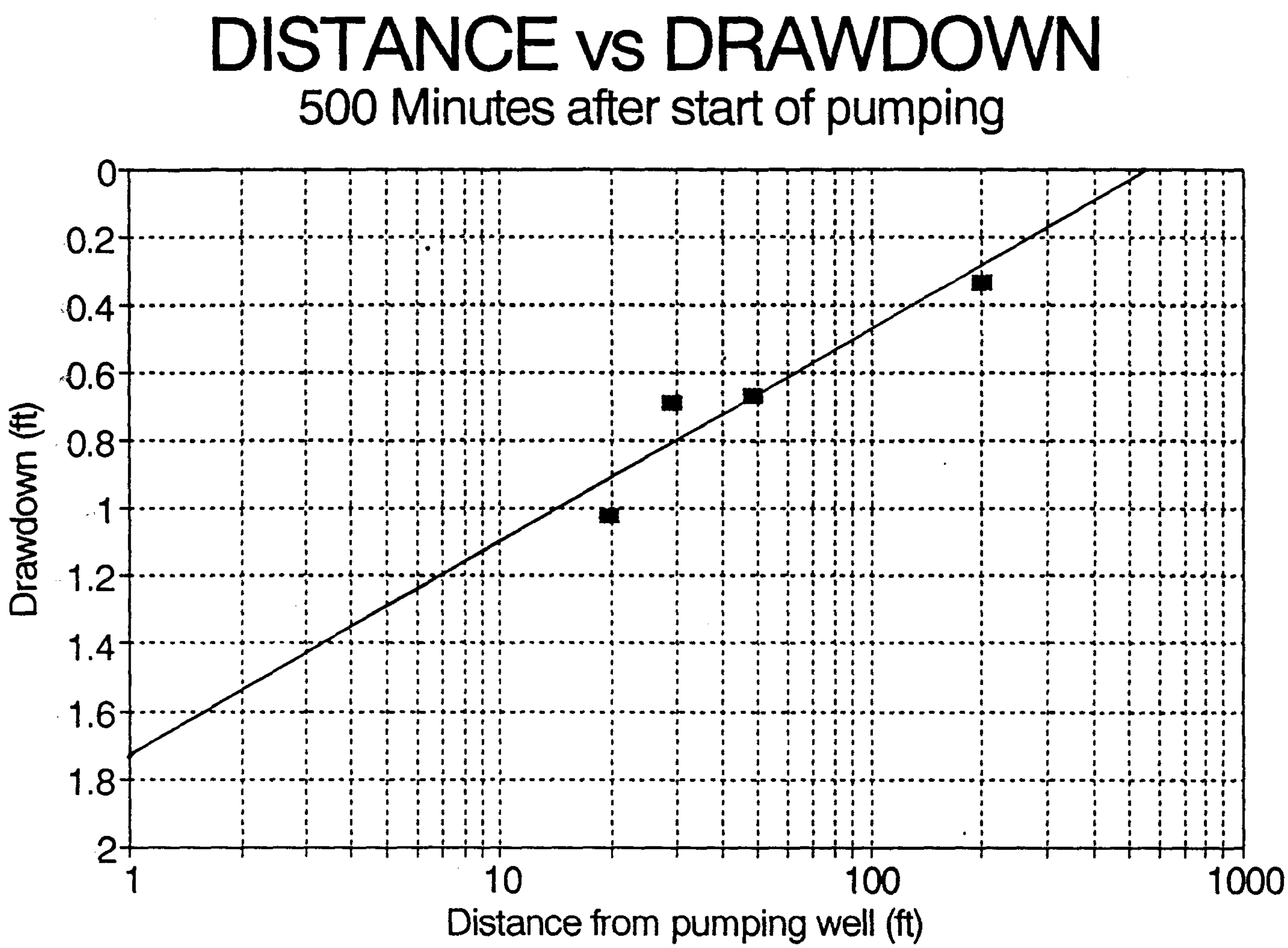


Figure 5-3

Jacob Distance-Drawdown Method for 500 Minutes

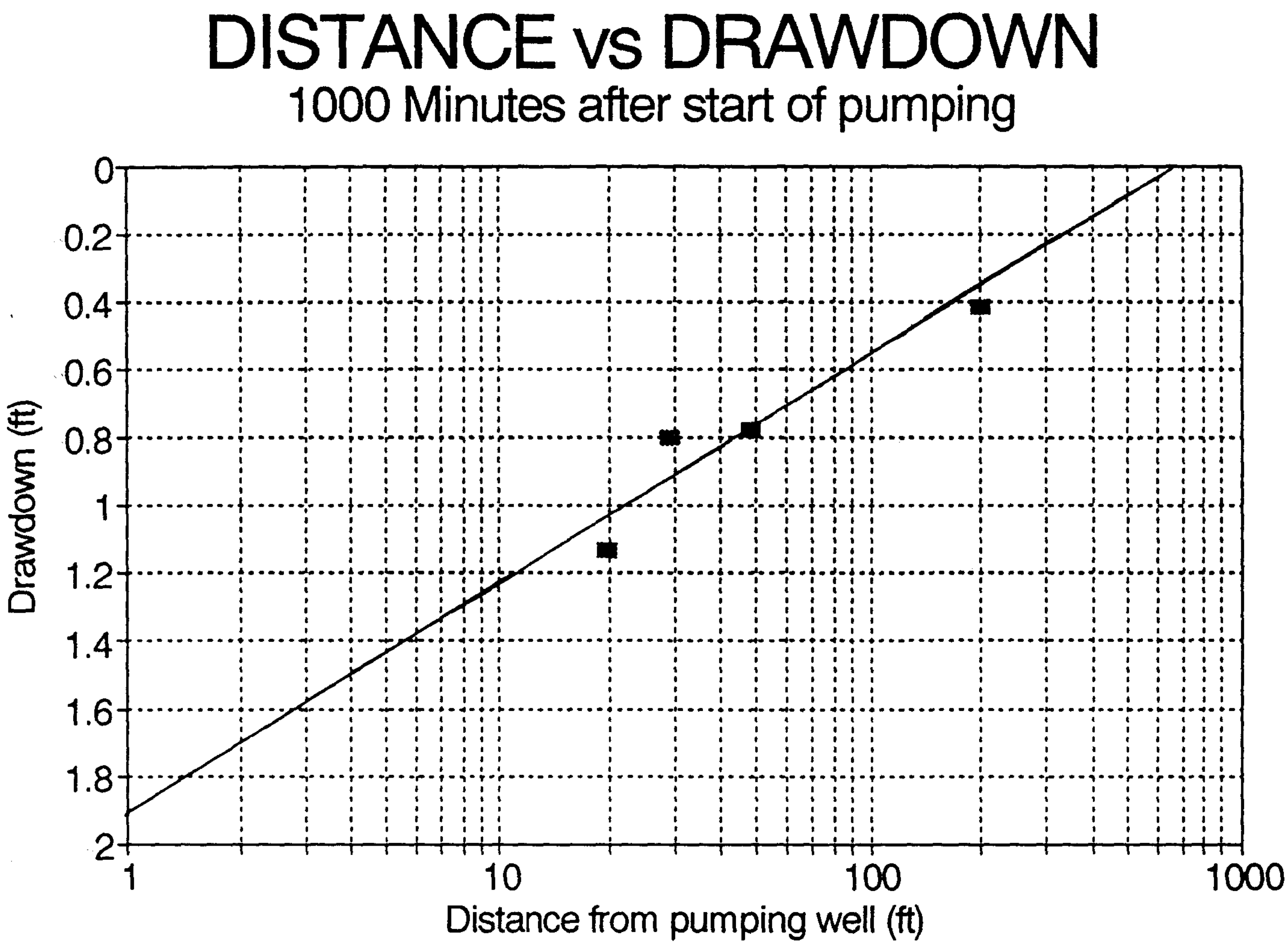


Figure 5-4

Jacob Distance-Drawdown Method for 1000 Minutes

at times 100, 500 and 1000 minutes. Table 5-3 contains the results of the test and data employed. The following equations were utilized to obtain horizontal conductivity, transmissivity and storativity.

$K_h = T/(D * 7.48)$

$T = 2.3Q/(2.25T * t * ds)$

$S = (2.25T * t)/r^2$

s' = Corrected drawdown (ft)

s = Drawdown (ft)

D = Aquifer saturated thickness = 96 ft

T = Transmissivity (gpd/ft)

Q = Discharge = 425 (gpm)

ds = Slope obtained from graph

r = X-intercept

t = Time

Table 5-3 Results of Jacob Distance Drawdown Method

Time Pumping (min)	Transmissivity (gpd/ft)	Horizontal Conductivity (ft/day)	Storativity	Well 3911	Well 3916	Well 3921	Well 3922
100	379,898	529	.0686	.7548	.4769	.4649	.1799
500	334,538	466	.1114	1.0197	.6931	.6659	.3397
1000	339,606	473	.1732	1.1369	.7973	.7772	.4171

5.2 Neuman Method

When using the Neuman Method it is necessary to deal with early and late drawdown data. The time-drawdown curve tends to make a S-shape, because of the delay to late drawdown response. This effect makes the Theis and Cooper-Jacob Methods seem erroneous. Aqtesolv 1.0 (Duffield and Rumbaugh III 1988) is used to arrive at the final estimated hydraulic parameters. Initial estimations for the Neuman Method will be deduced from the Theis and Cooper-Jacob Methods, which are located in Appendix A. The Neuman Method through Aqtesolv is an iterative analysis with four unknowns. The iterative process takes hours, so good initial estimates of the parameters are important. The governing equations for the Neuman Method are listed below.

$s = Q/(12.56K_h * D) * W(u_{a,b},B,S/S_y,b/D,d/D,z/D)$

$u_a = r^2 * S/(4K_h * D * t)$ = For early drawdown data

$u_b = r^2 * S_y/(4K_h * D * t)$ = For late drawdown data

s = Drawdown (ft)

Q = Discharge (ft^3/day)

t = Time

K_h = Horizontal hydraulic conductivity (ft/day)

$W(u_a...)$ = Well function based on six independent dimensionless parameters

S_y = Specific yield

S = Storativity

b = Water table distance to bottom of pumping well screen (ft)

d = Water table distance to bottom of pumping well screen (ft)

D = Aquifer saturated thickness (ft)

z = distance of bottom of monitor well to bottom of aquifer(ft)

T = Transmissivity (ft^2/min)

r = Distance to RW-4 (ft)

B = Delay factor

The data for the Neuman Method is in Appendix B. As shown in Appendix B, the drawdown for the first minute is weighted .25, and then weighted .5 until 10 minutes. The rest of the data is weighted at 1. The weight of the late time data was based on two effects. The initial discharge rate for the pumping test was 600 gpm, and was reduced to a constant 425 gpm during the first minute. The effects of well storage is significant in the early time data. After 39 minutes the well storage effect is minimal.

The horizontal conductivity may be calculated from the Neuman Method results. The equation is listed below.

$K_h = T * 1440/D$

The results of the analysis are listed in Table 5-4. The final matched curves are depicted in Figures 5-1 through 5-8.

Table 5-4 Neuman Method Results

Well #	Transmissivity (gpd/ft)	Storativity	Specific Yield	Horizontal Conductivity (ft/day)
3910	376,238	.03339	.01124	524
3916	534,585	.01390	.01220	744
3917	461,632	.00415	.05951	667
3918	459,158	.09315	.07726	640
3921	439,390	.01516	.01288	612
3922	390,564	.03458	.02913	544
3923	412,408	.01391	.01221	596

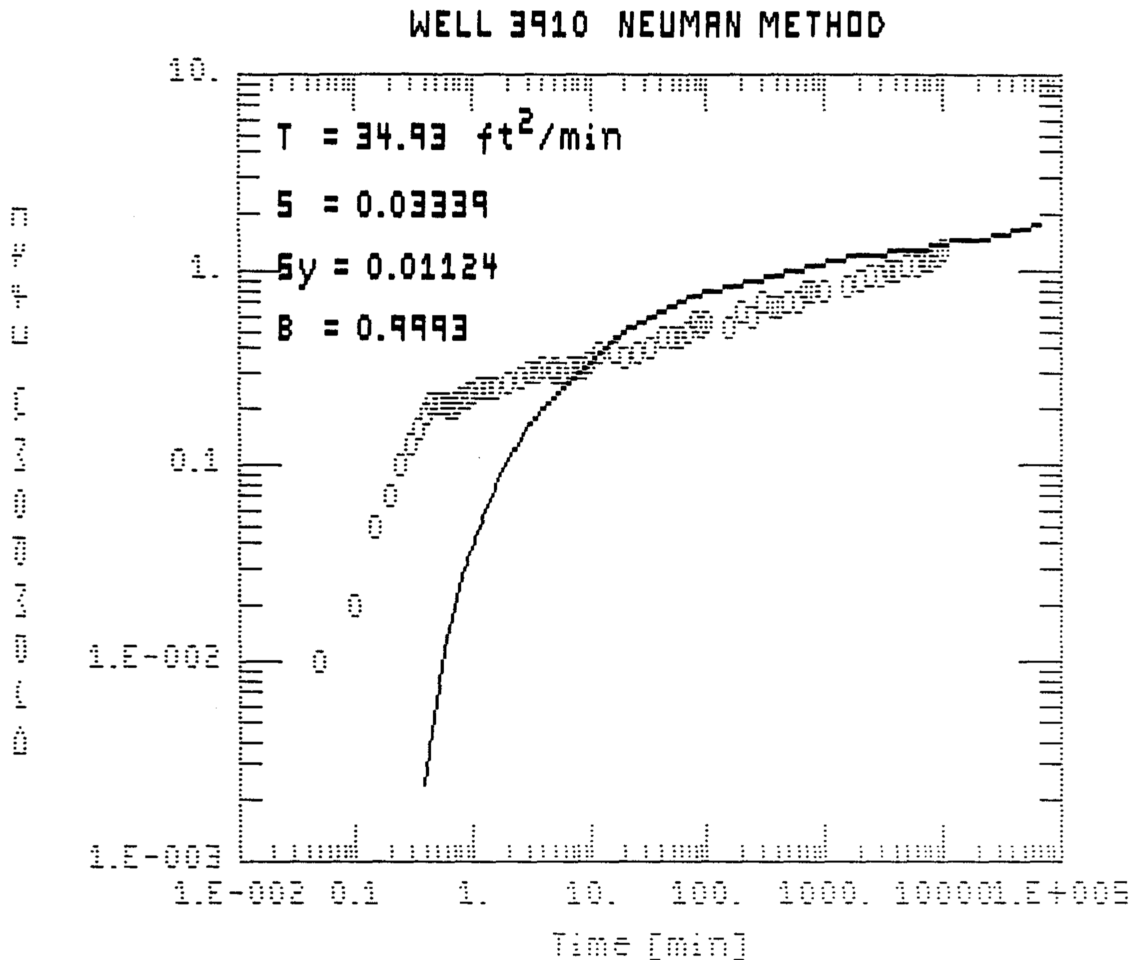


Figure 5-5
Neuman Method for Well 3910

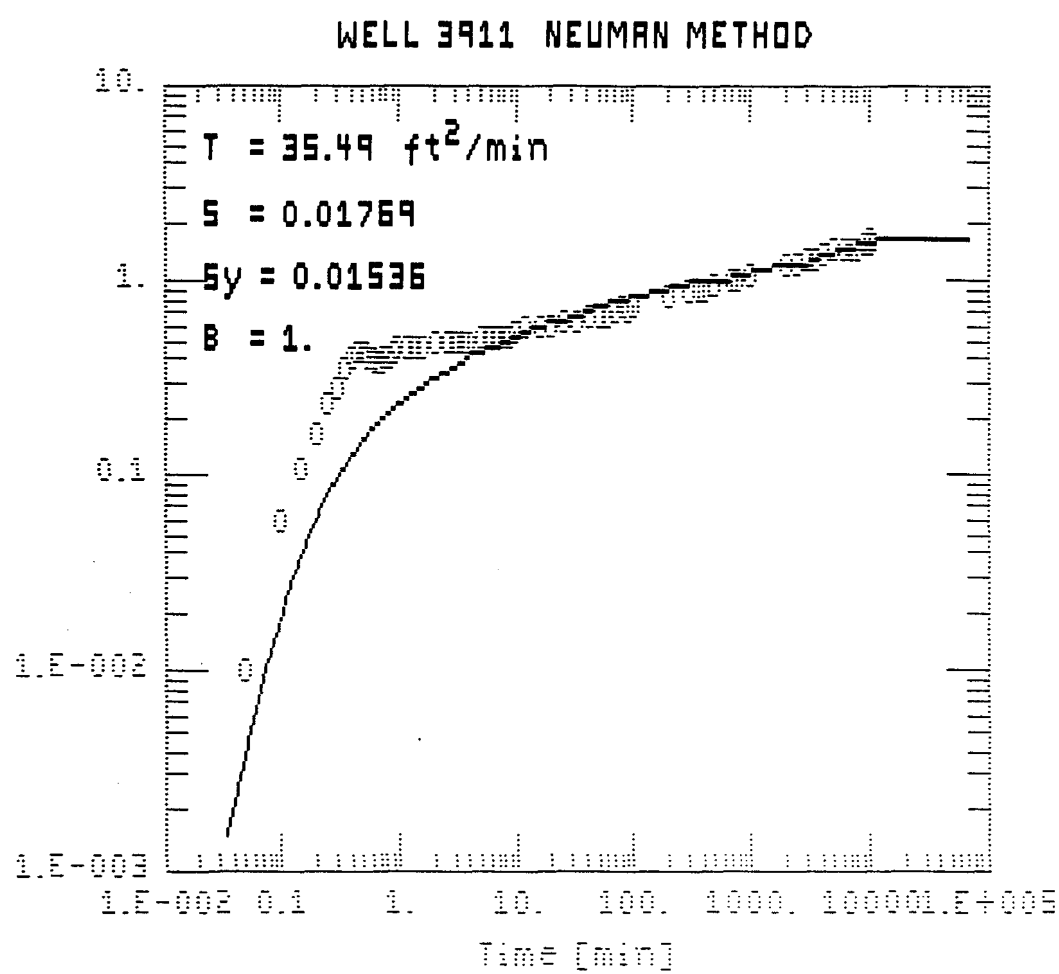


Figure 5-6
Neuman Method for Well 3911

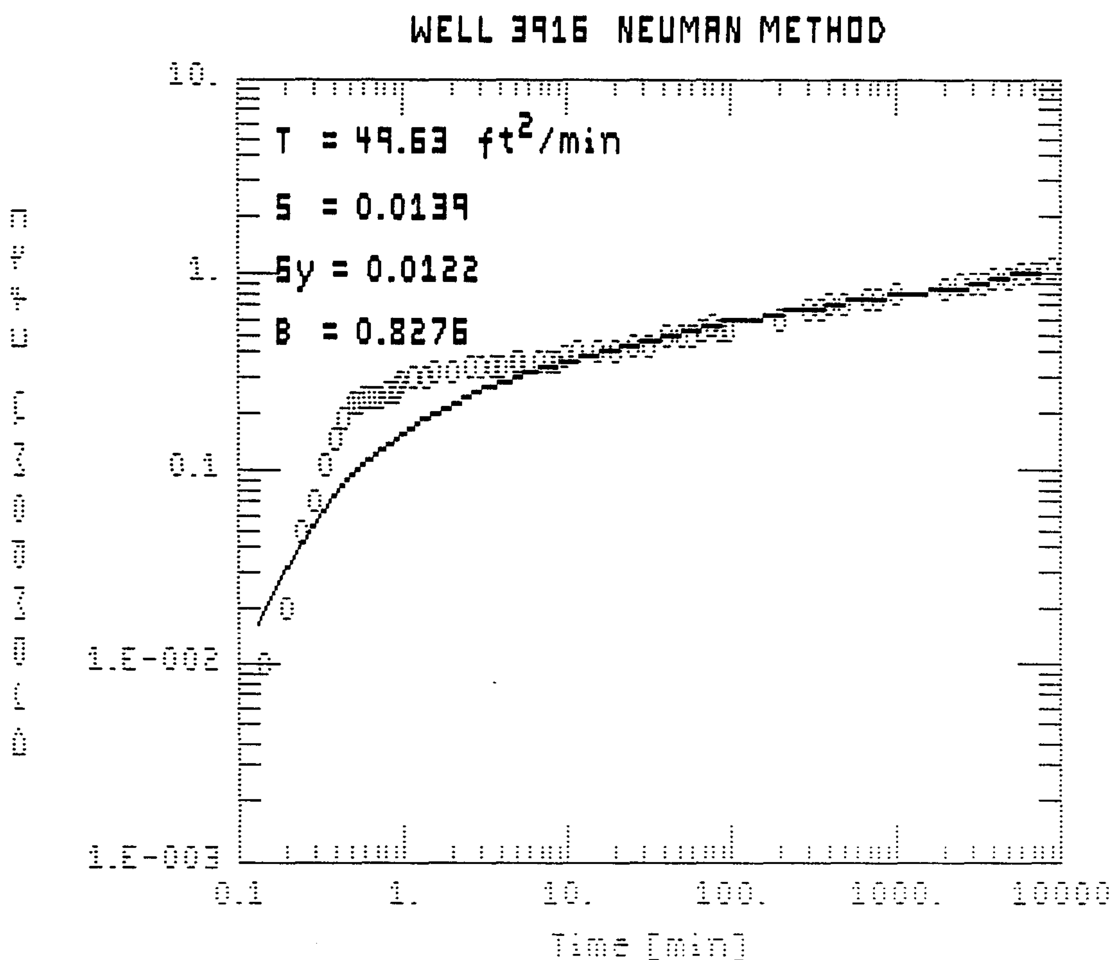


Figure 5-7
Neuman Method for Well 3916

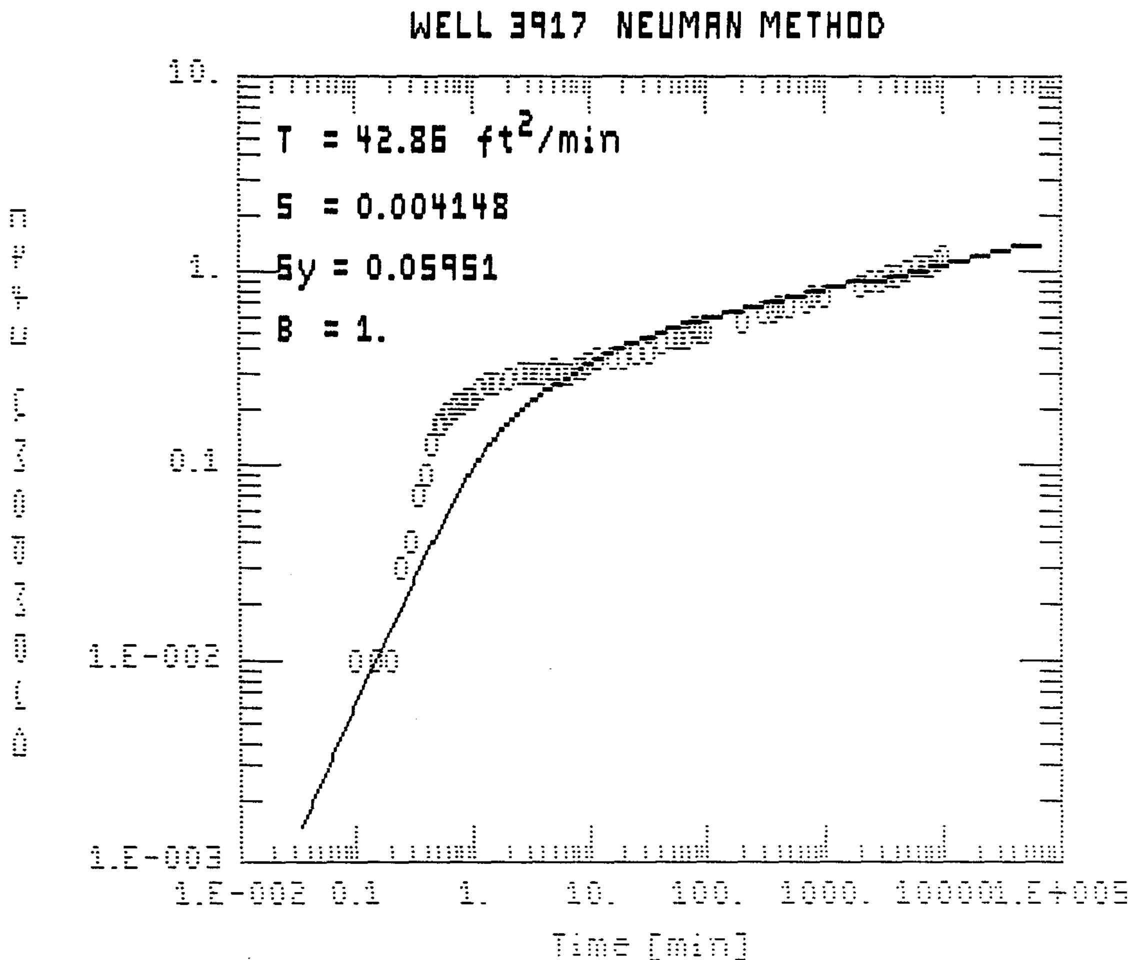


Figure 5-8
Neuman Method for Well 3917

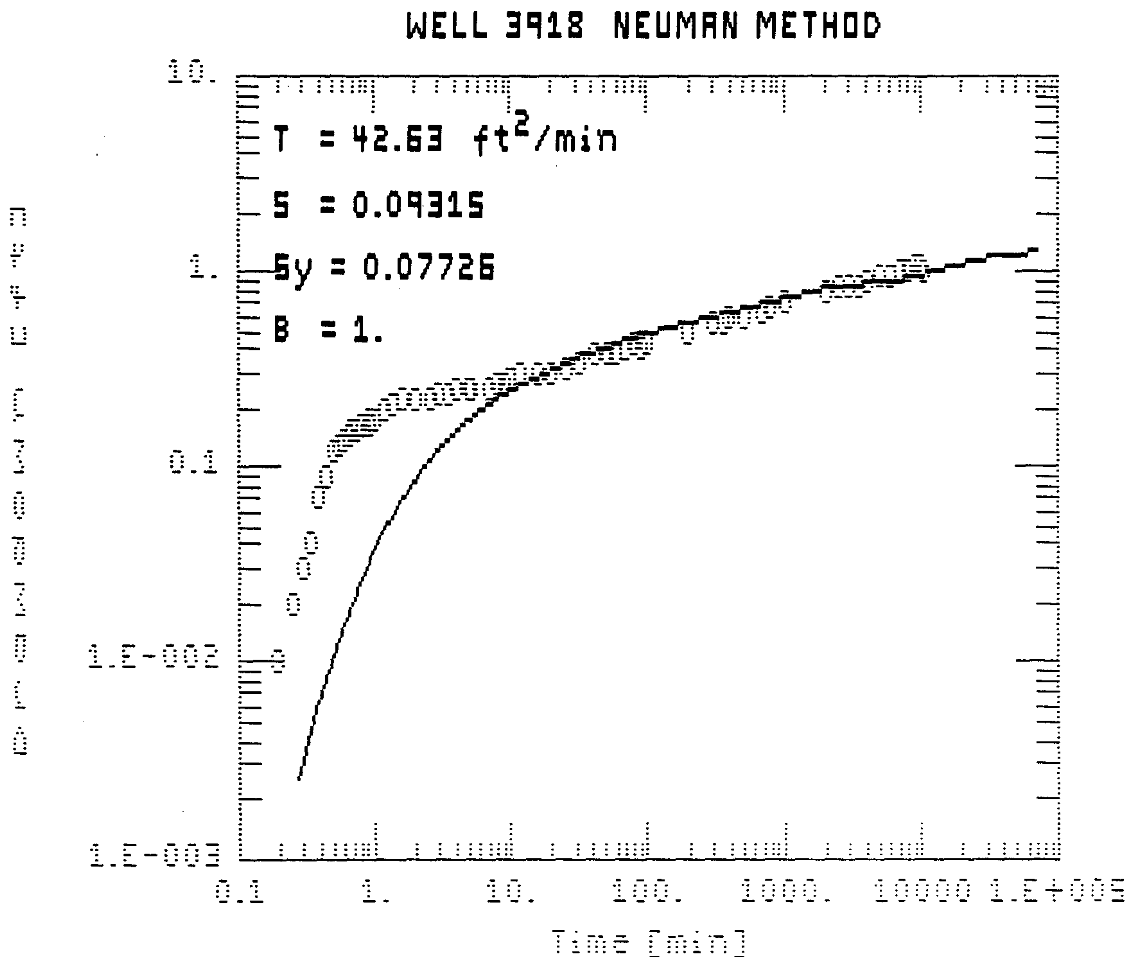


Figure 5-9
Neuman Method for Well 3918

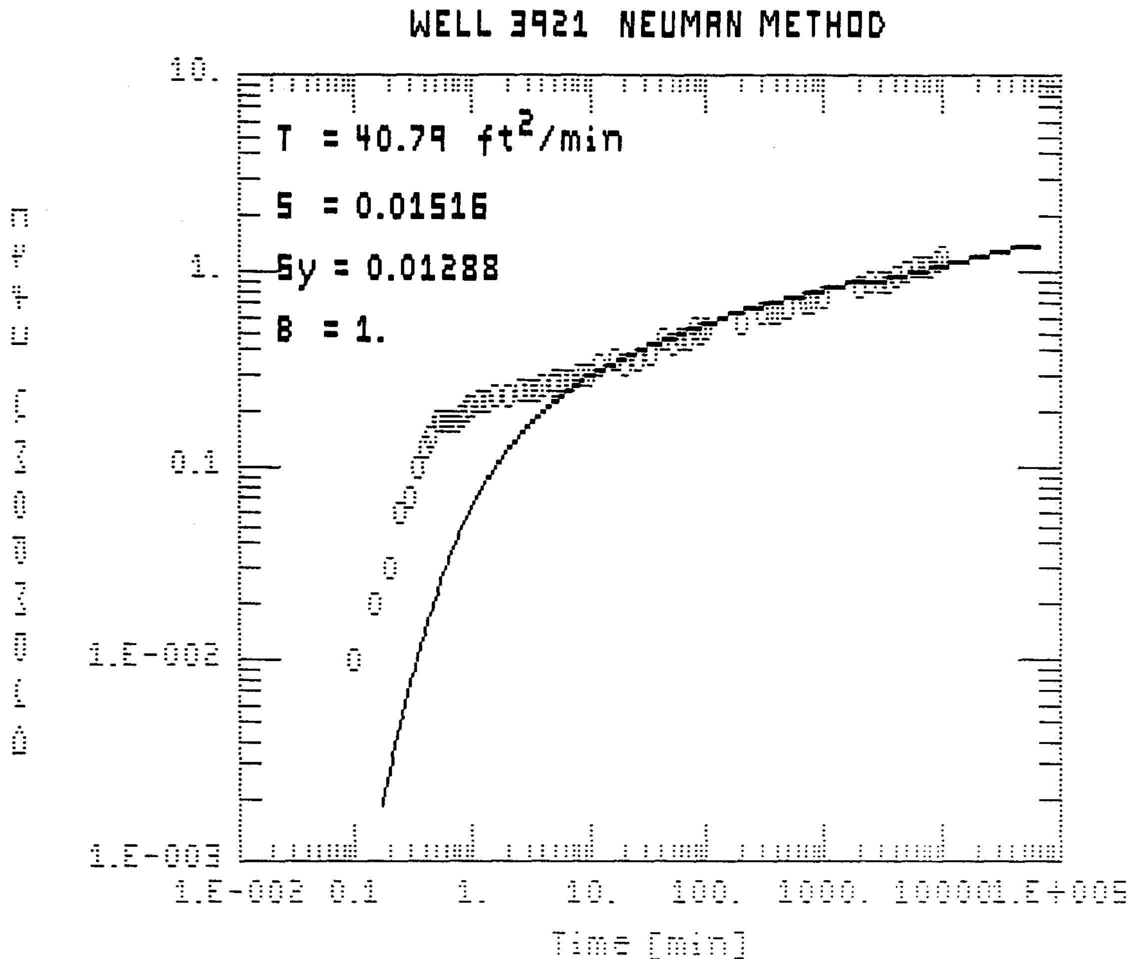


Figure 5-10
Neuman Method for Well 3921

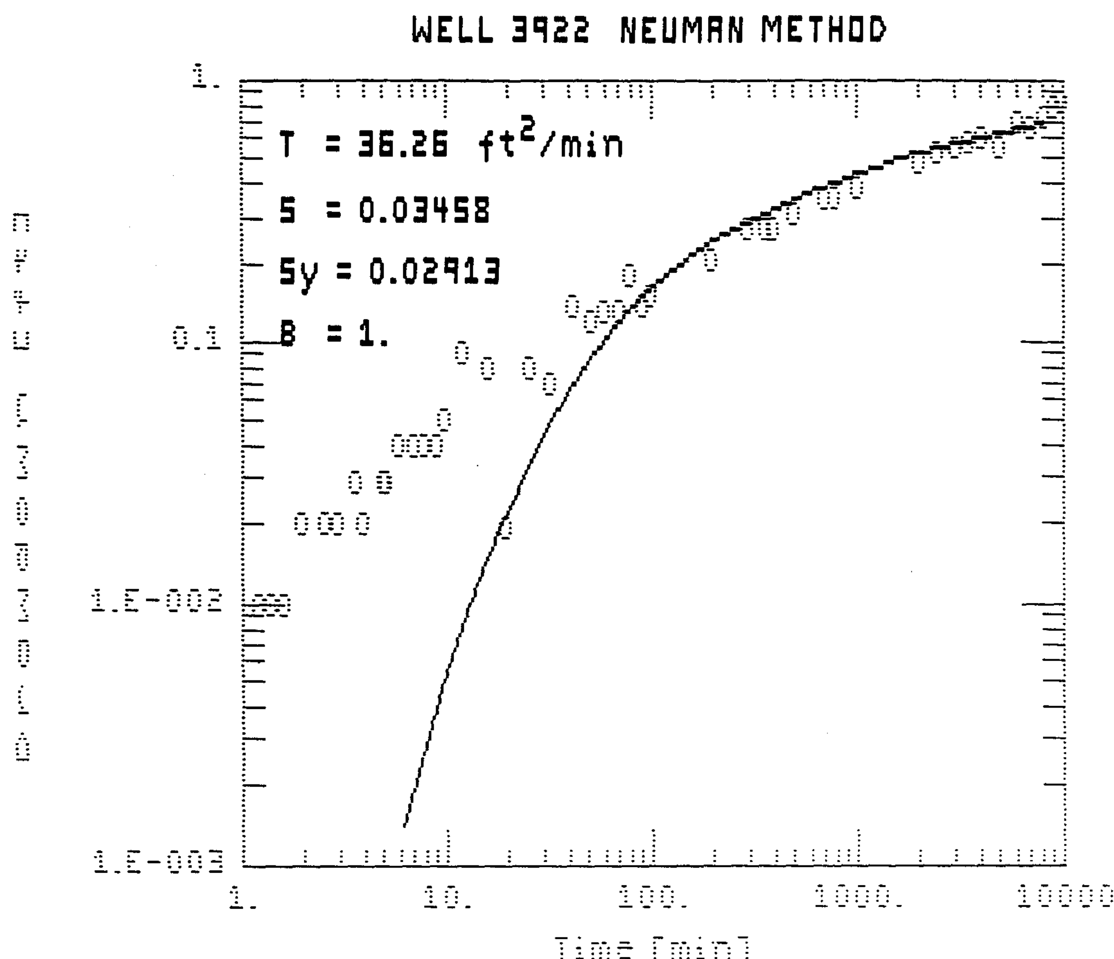


Figure 5-11
Neuman Method for Well 3922

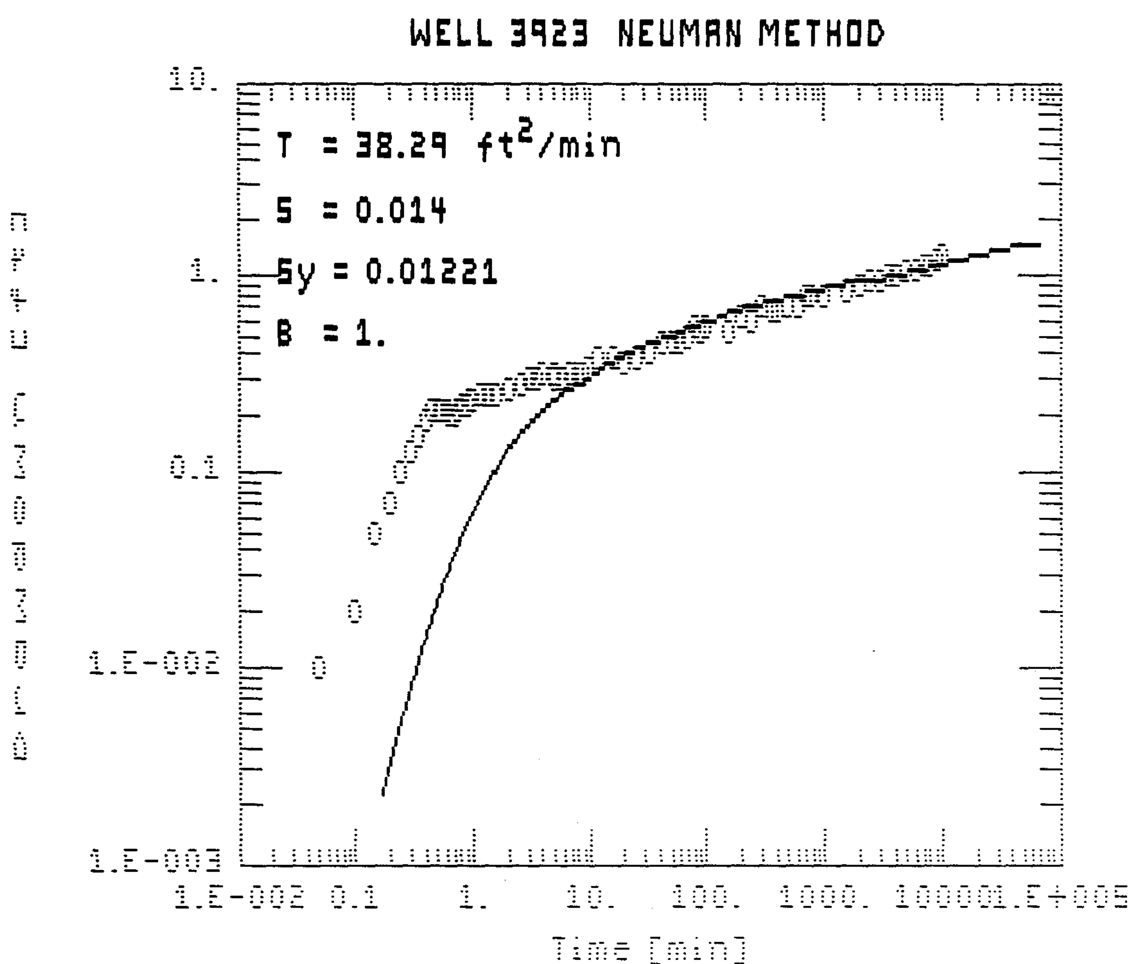


Figure 5-12
Neuman Method for Well 3923

6.0 SUMMARY

The Great Miami Aquifer represents a significant water supply for the surrounding Femp area. The aquifer flows directly below Fernald site. The Fernald site has the potential of major contamination in the aquifer. Thus far the contamination levels to the aquifer have remained predominately in the proposed USEPA standards.

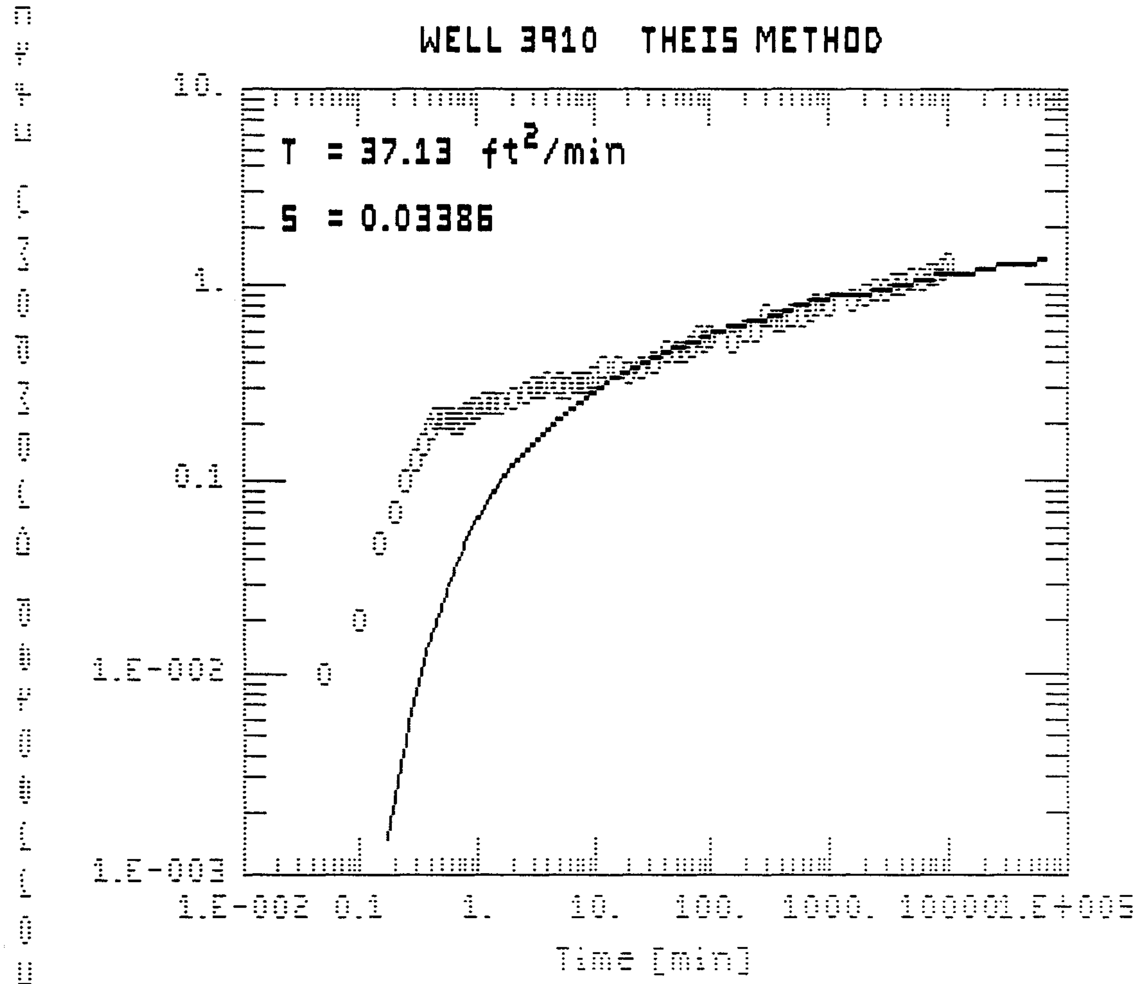
The Great Miami Aquifer is a relatively permeable sand and gravel aquifer. A relatively impermeable clay layer separates the upper and lower aquifer. Groundwater enters the Femp from three separate directions. It exits toward the Great Miami River to the south and SOWC production wells to the east.

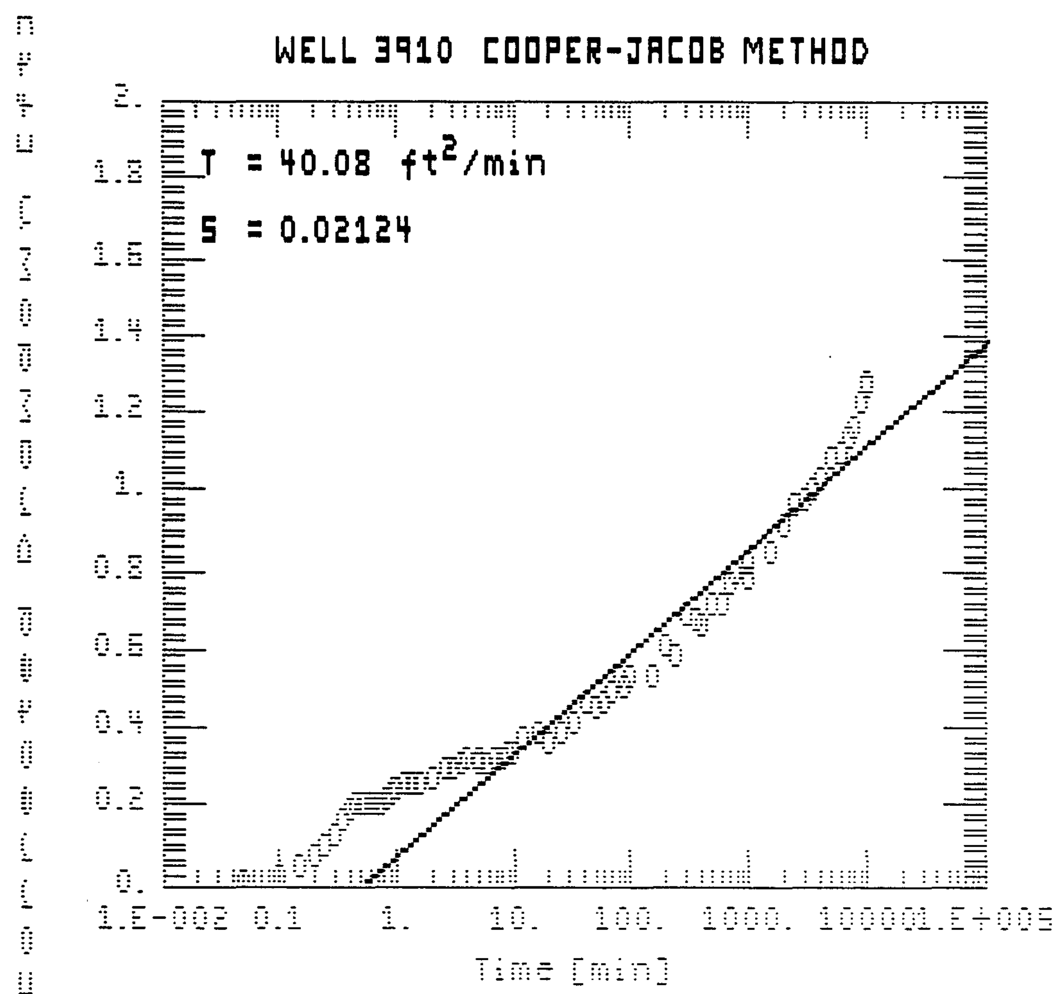
The overlying glacial overburden acts as an aquitard in most areas of the Femp. Paddy Run erosion of the glacial overburden allows it to interact with the Great Miami Aquifer, affecting groundwater flow and discharge. The interaction is observed in the Type III/I. There is relatively little recharge of the aquifer due to the presence of clayey till. As discussed, recharge varies due to seasonal changes and regional pumping of the aquifer.

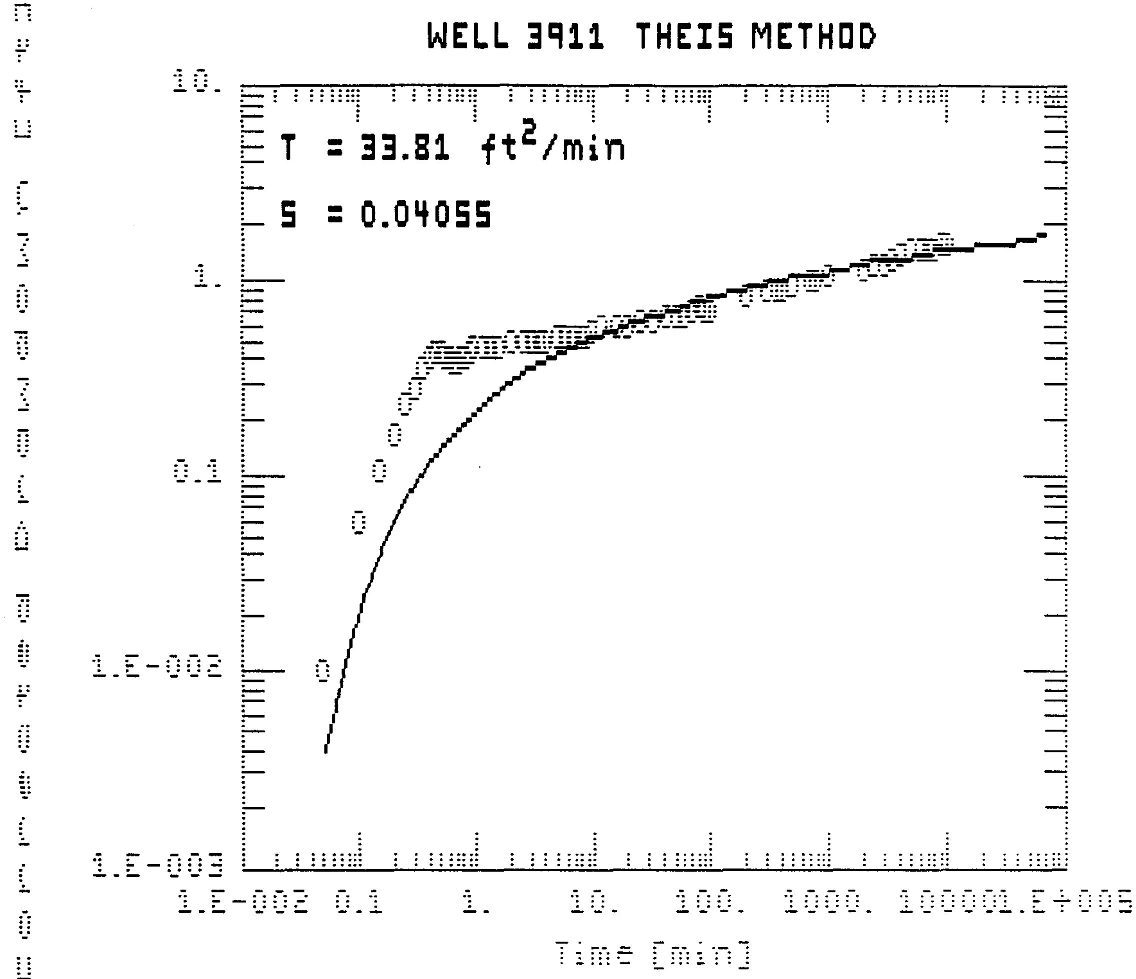
Aquifer tests have provided estimated parameters for the aquifer. The Theis, Cooper-Jacob, Jacob Distance-Drawdown and the Neuman Methods were performed. The transmissivity seems to range between 340,000 gpd/day to 530,000 gpd/day, with the storativity between .00415 to .1712. The specific yield and horizontal conductivity were found to range from .01124 to .07726 and 473 to 744 ft/day. The results of these tests will hopefully help model a efficient contamination remediation system.

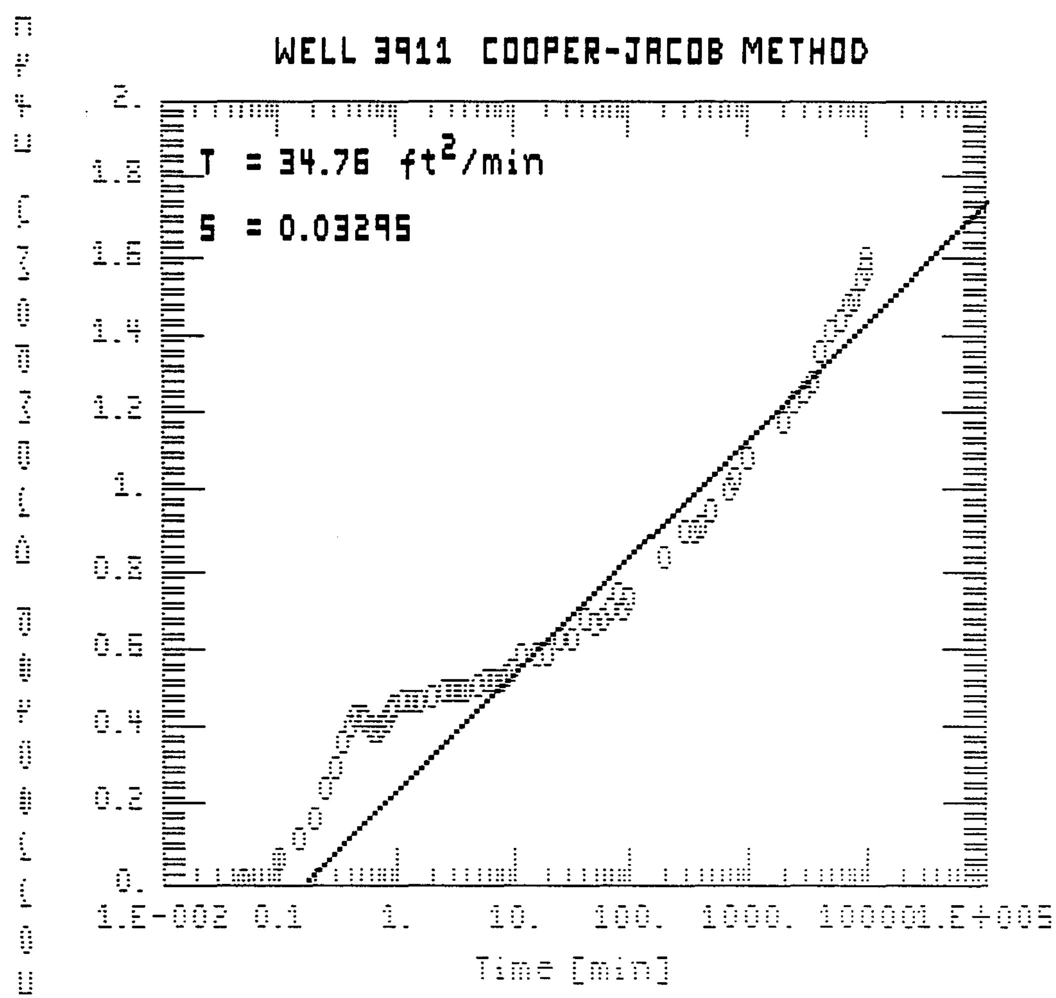
APPENDIX A

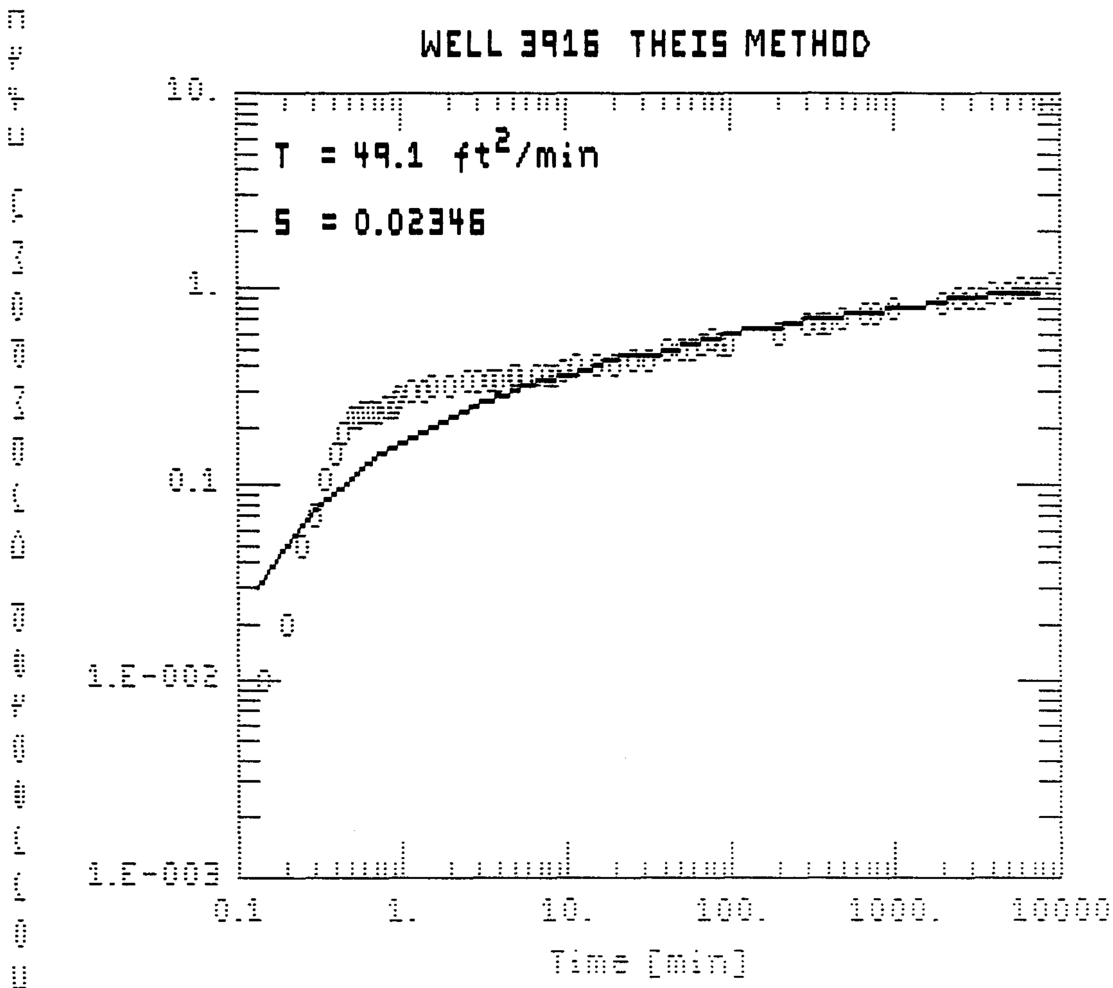
Theis and Cooper-Jacob Method

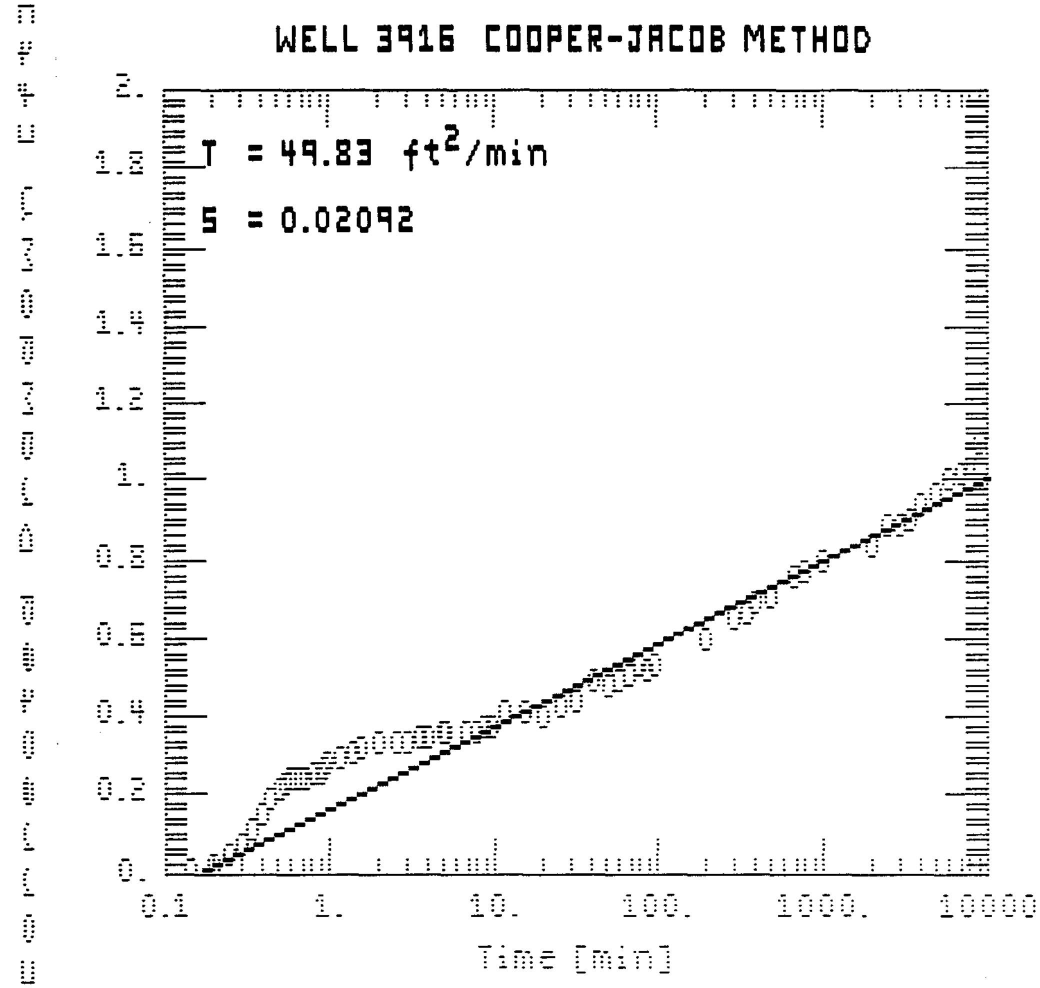

WELL 3910 THEIS METHOD
T = 37.13 ft²/min
S = 0.03386
10.
1.
0.1
1.E-002
1.E-003
1.E-002 0.1 1. 10. 100. 1000. 10000 1.E+005
Time [min]

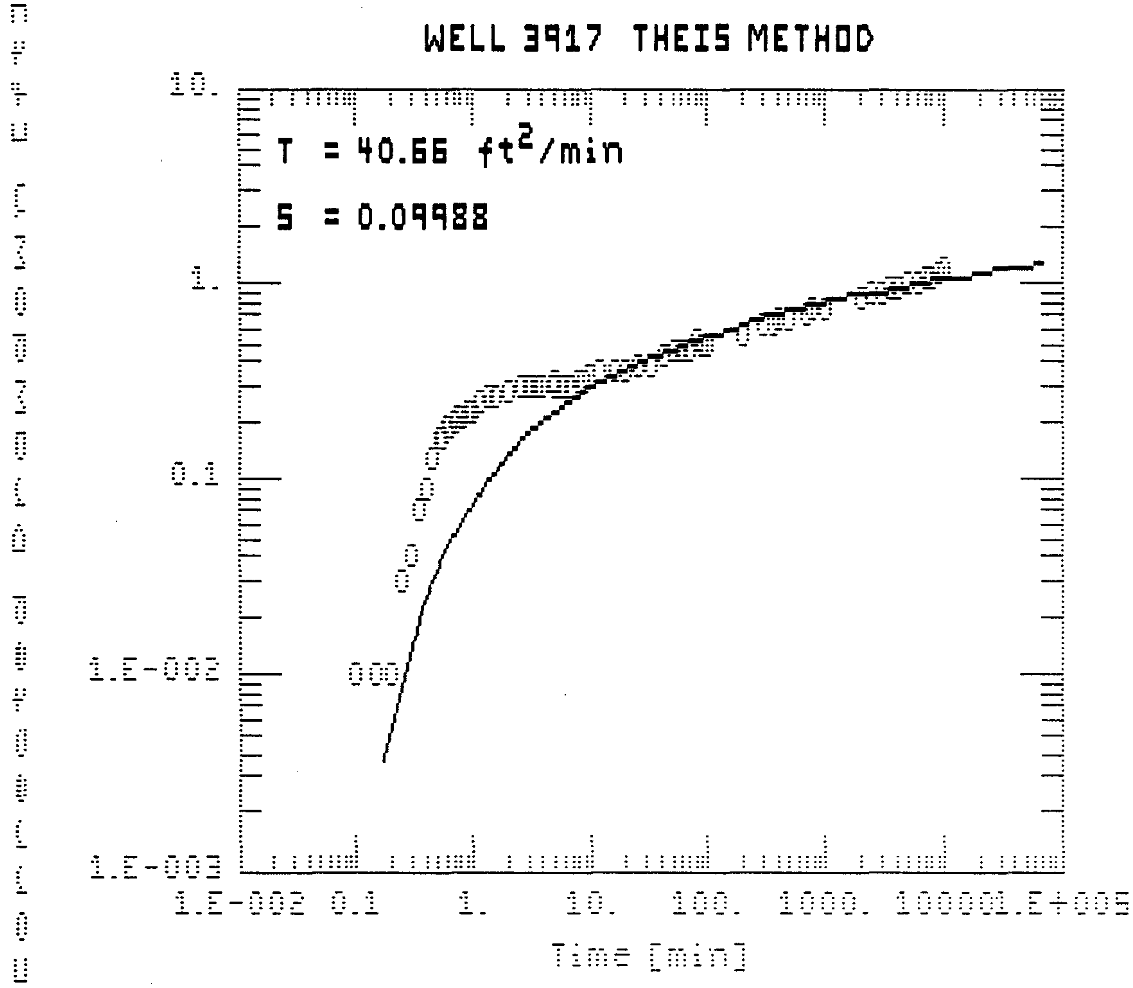

WELL 3910 COOPER-JACOB METHOD
T = 40.08 ft2/min
S = 0.02124
2.
1.8
1.6
1.4
1.2
1.
0.8
0.6
0.4
0.2
0.
1.E-002 0.1 1. 10. 100. 1000. 100001.E+005
Time [min]
Corrected Drawdown [ft]

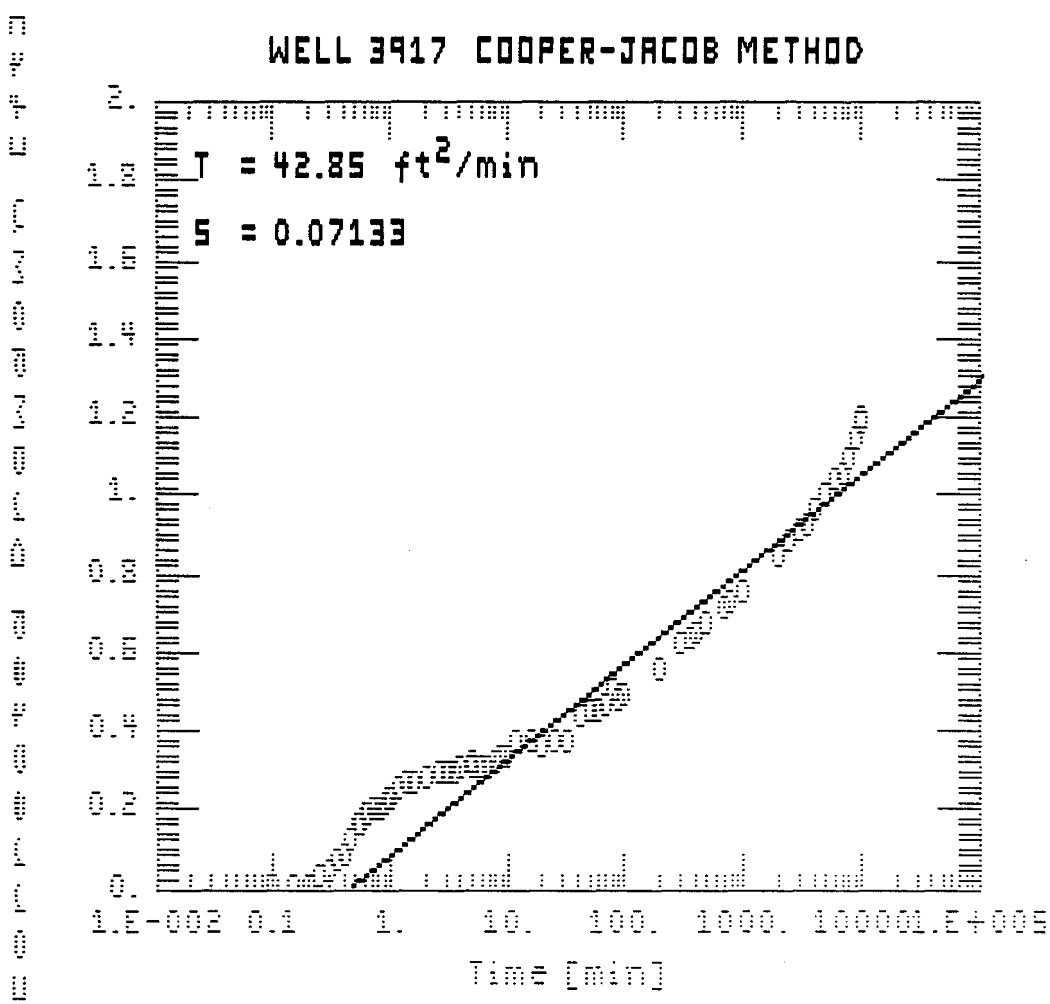

WELL 3911 THEIS METHOD
T = 33.81 ft²/min
S = 0.04055
10.
1.
0.1
1.E-002
1.E-003
1.E-002 0.1 1. 10. 100. 1000. 100001.E+005
Time [min]

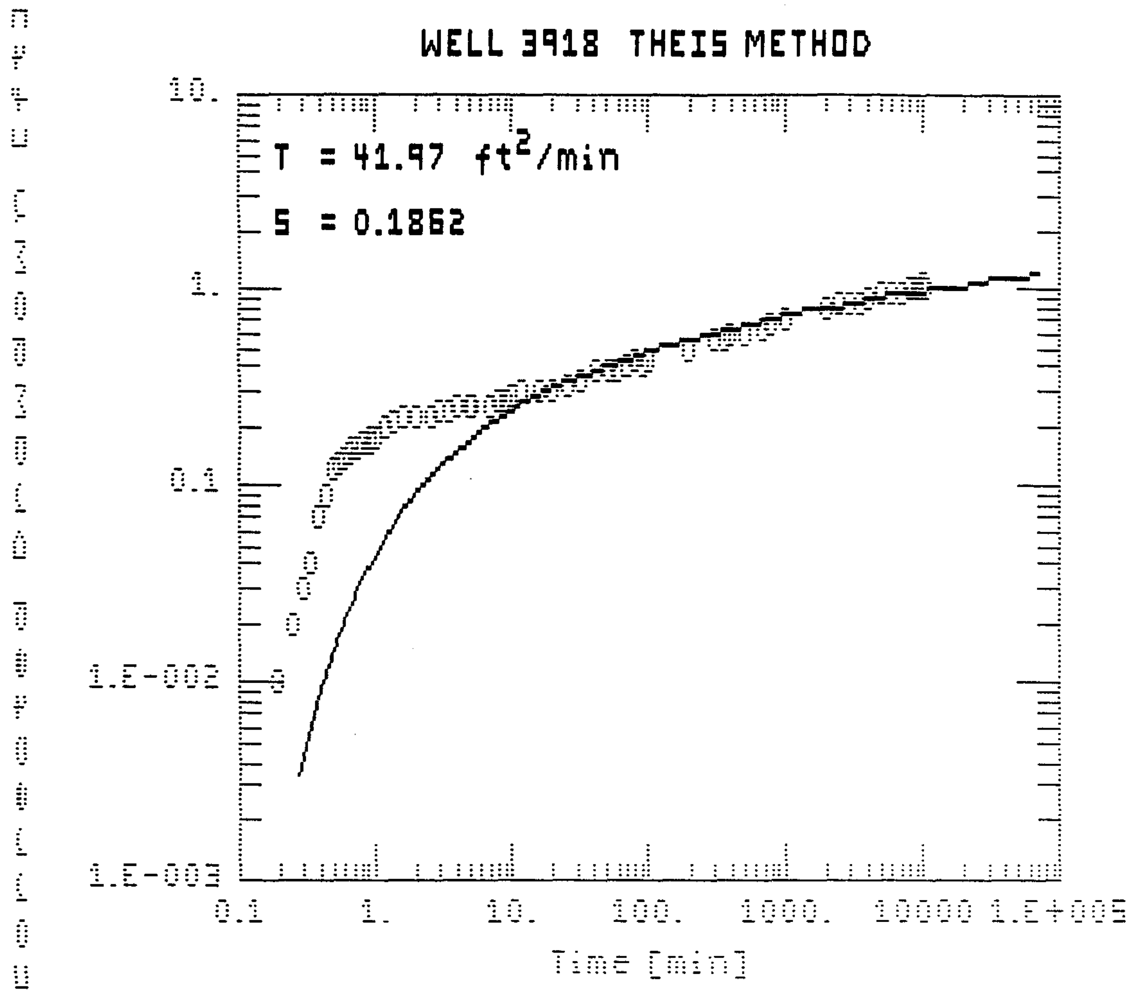

WELL 3911 COOPER-JACOB METHOD
T = 34.76 ft^2/min
S = 0.03295
Corrected Drawdown [ft]
0. 0.2 0.4 0.6 0.8 1. 1.2 1.4 1.6 1.8 2.
1.E-002 0.1 1. 10. 100. 1000. 10000 1.E+005
Time [min]

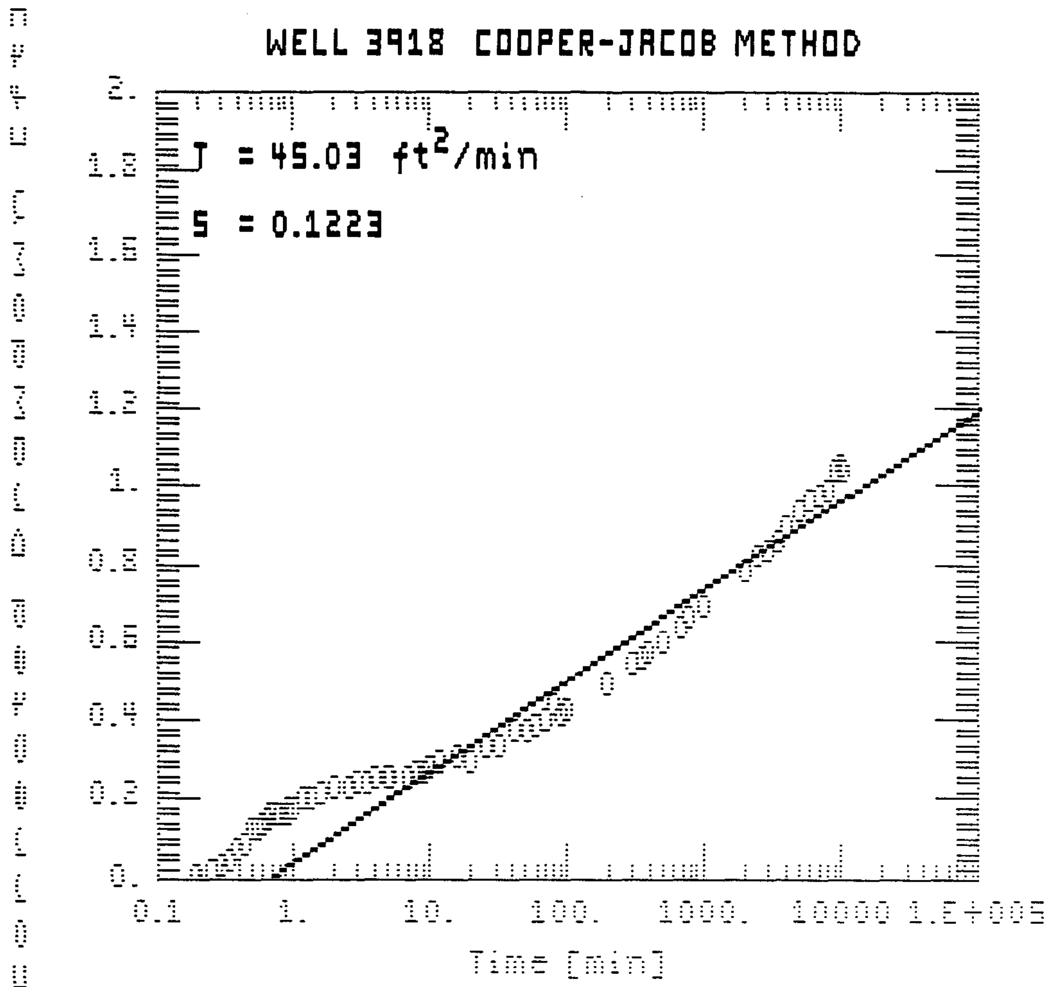

WELL 3916 THEIS METHOD
T = 49.1 ft2/min
S = 0.02346
10.
1.
0.1
1.E-002
1.E-003
0.1
1.
10.
100.
1000.
10000
Time [min]
Corrected Drawdown [ft]

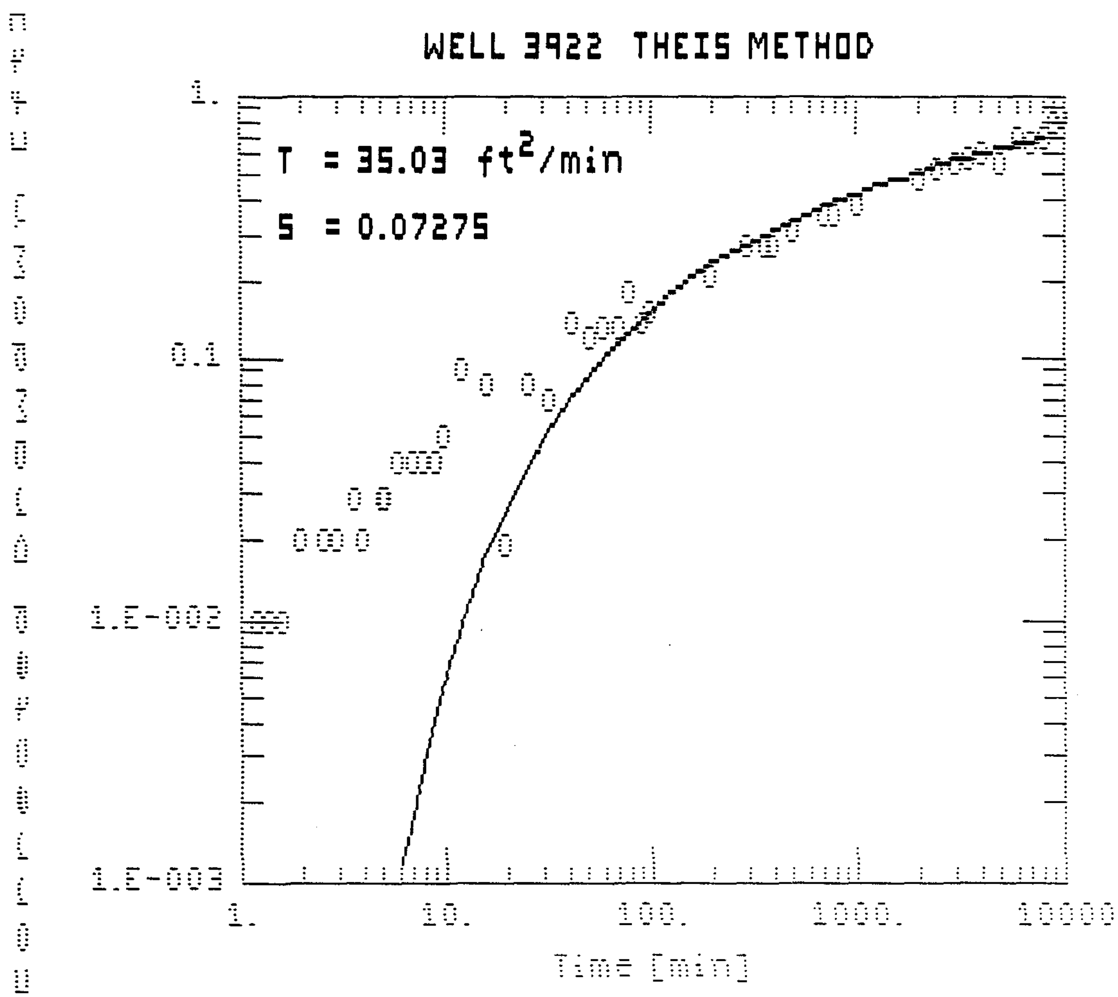

WELL 3916 COOPER-JACOB METHOD
T = 49.83 ft2/min
S = 0.02092
Corrected Drawdown [ft]
0.
0.2
0.4
0.6
0.8
1.
1.2
1.4
1.6
1.8
2.
0.1
1.
10.
100.
1000.
10000
Time [min]

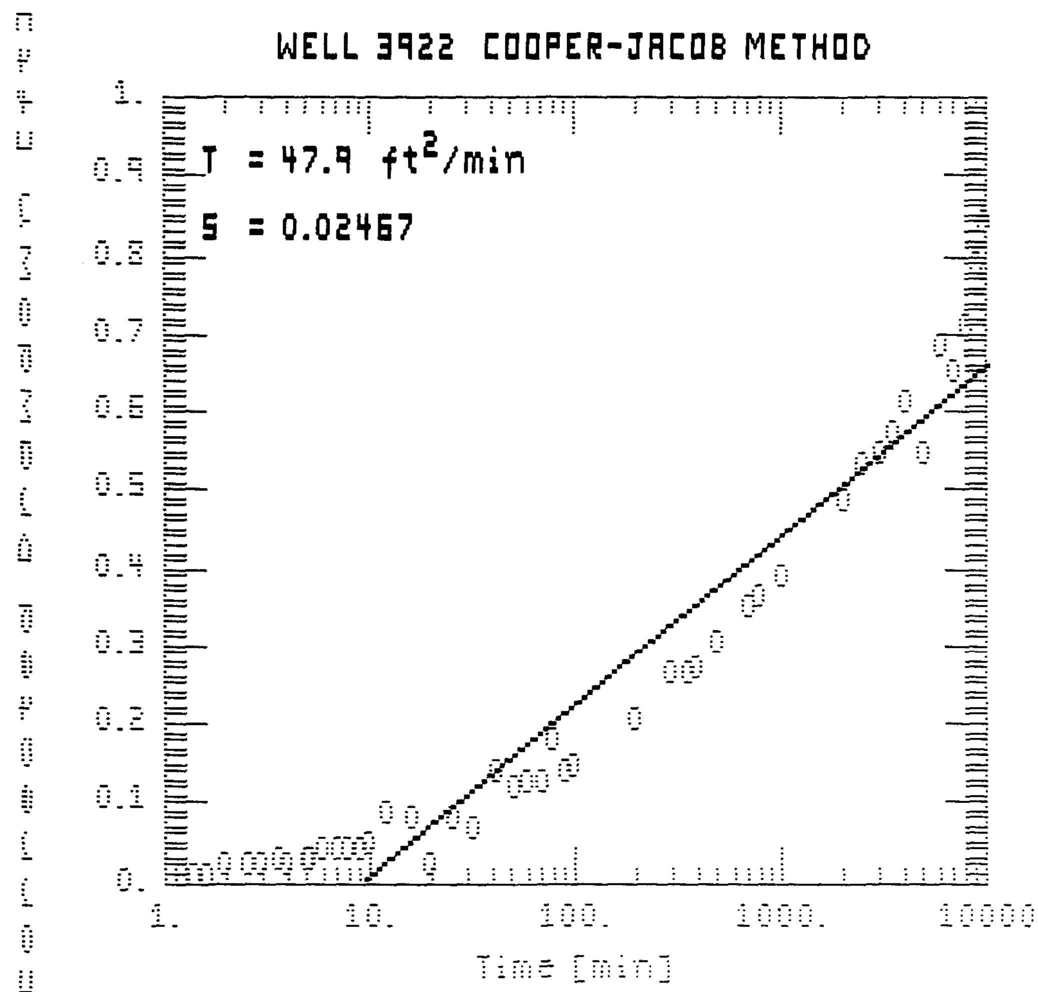

WELL 3917 THEIS METHOD
T = 40.66 ft^2/min
S = 0.09988
10.
1.
0.1
1.E-002
1.E-003
1.E-002 0.1 1. 10. 100. 1000. 100001.E+005
Time [min]
Corrected Drawdown [ft]


WELL 3917 COOPER-JACOB METHOD
T = 42.85 ft^2/min
S = 0.07133
2.
1.8
1.6
1.4
1.2
1.
0.8
0.6
0.4
0.2
0.
1.E-002 0.1 1. 10. 100. 1000. 10000 1.E+005
Time [min]
Corrected Drawdown [ft]

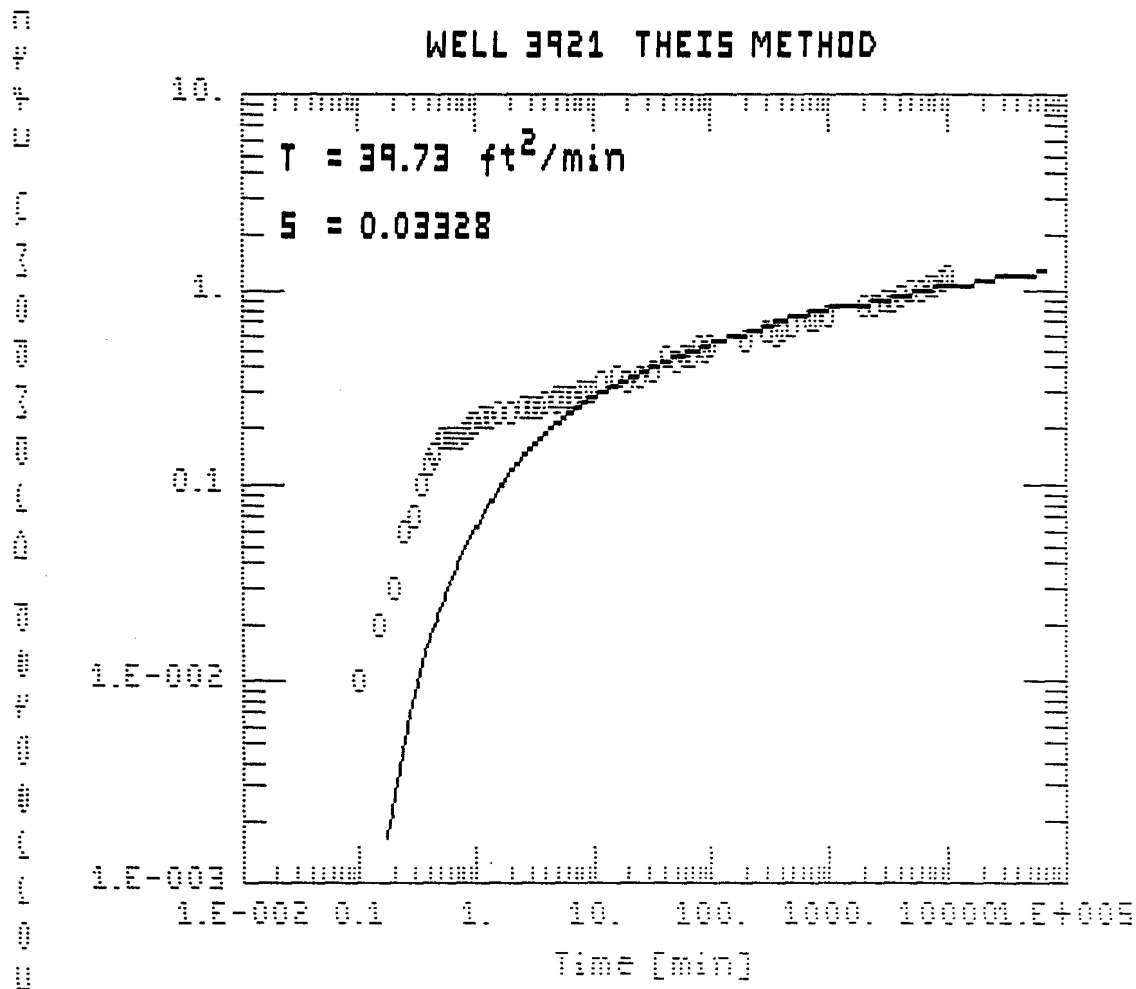

WELL 3918 THEIS METHOD
T = 41.97 ft2/min
S = 0.1862
10.
1.
0.1
1.E-002
1.E-003
0.1
1.
10.
100.
1000.
10000
1.E+005
Time [min]
Corrected Drawdown [ft]

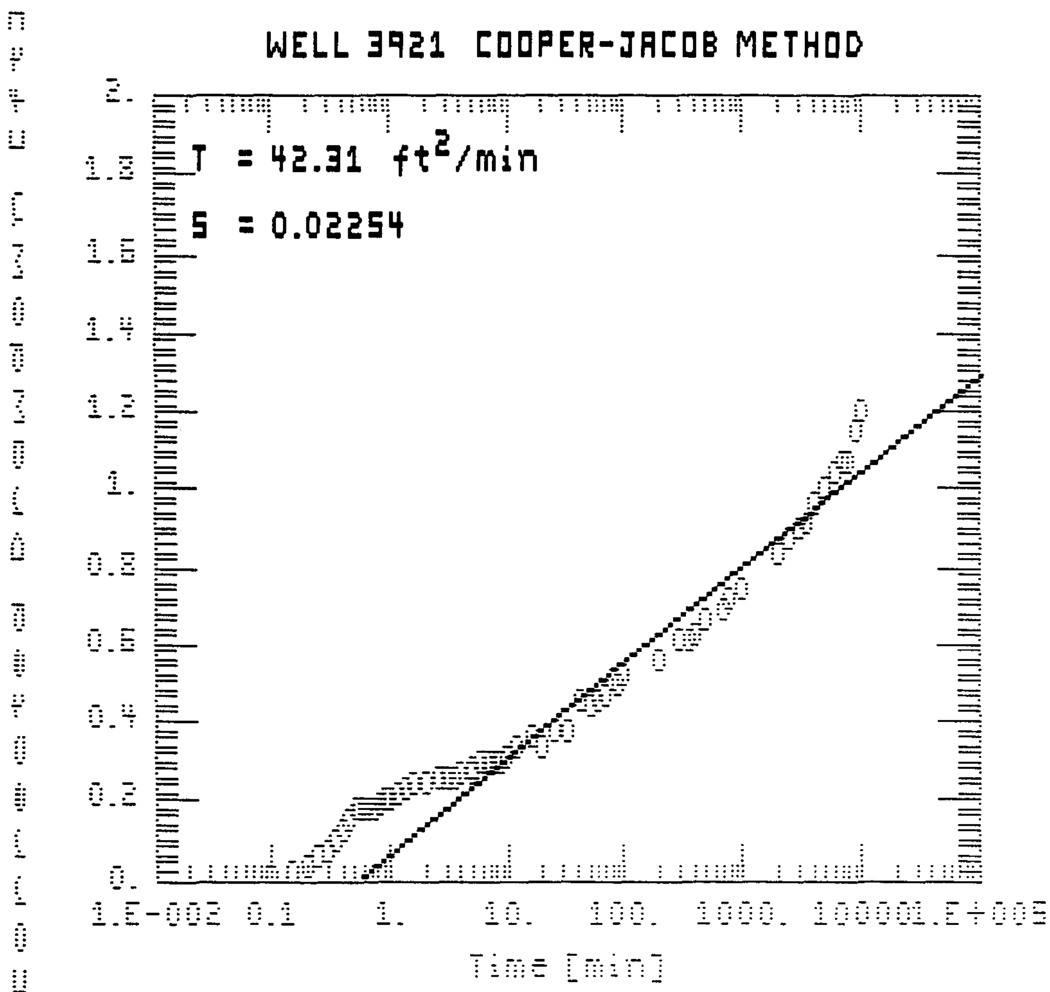

WELL 3918 COOPER-JACOB METHOD
T = 45.03 ft²/min
S = 0.1223
2.
1.8
1.6
1.4
1.2
1.
0.8
0.6
0.4
0.2
0.
0.1
1.
10.
100.
1000.
10000
1.E+005
Time [min]

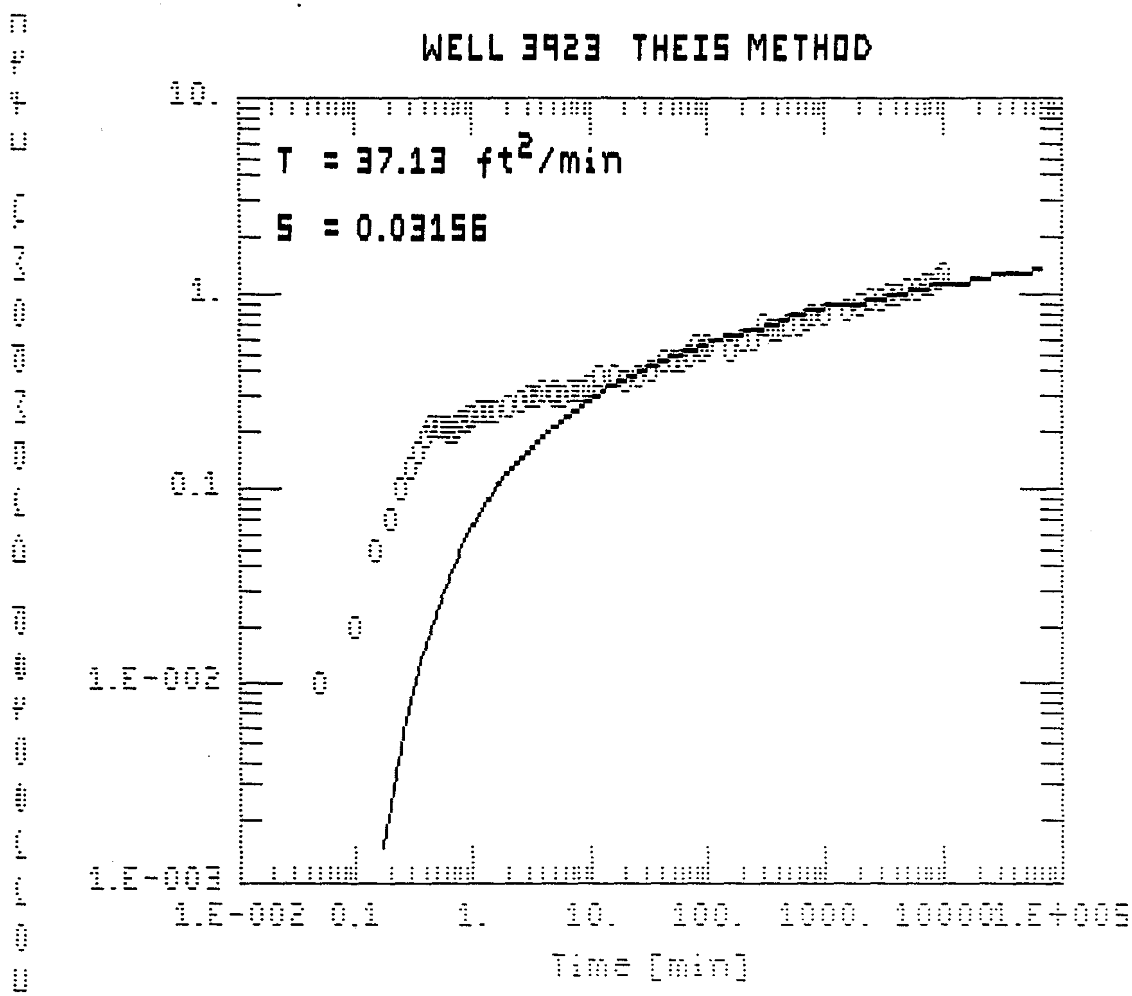

WELL 3922 THEIS METHOD
T = 35.03 ft2/min
S = 0.07275
1.
0.1
1.E-002
1.E-003
1.
10.
100.
1000.
10000
Time [min]
Corrected Drawdown [ft]

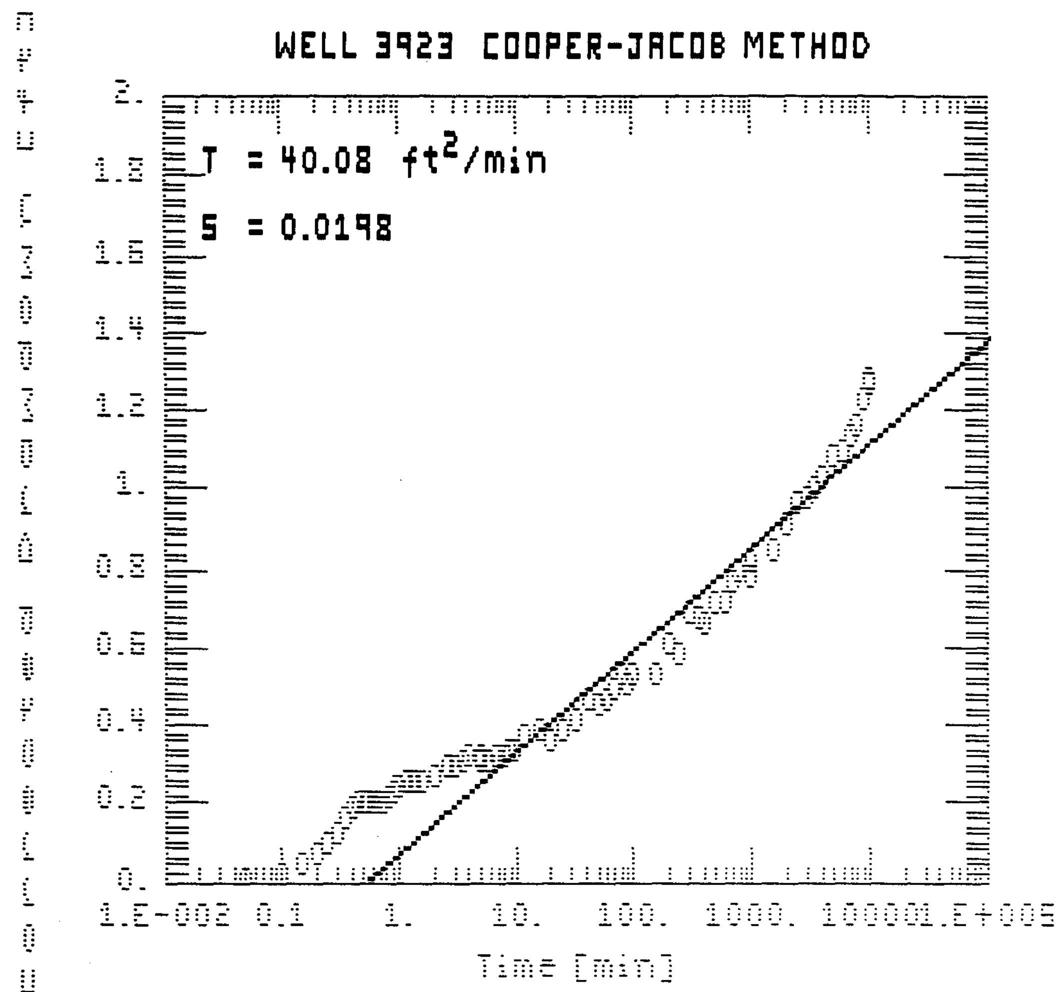


WELL 3922 COOPER-JACOB METHOD
T = 47.9 ft²/min
S = 0.02467
1.
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.
1.
10.
100.
1000.
10000
Time [min]
Corrected Drawdown [ft]


WELL 3921 THEIS METHOD
T = 39.73 ft2/min
S = 0.03328
10.
1.
0.1
1.E-002
1.E-003
1.E-002 0.1 1. 10. 100. 1000. 100001.E+005
Time [min]
Corrected Drawdown [ft]


WELL 3921 COOPER-JACOB METHOD
T = 42.31 ft²/min
S = 0.02254
2.
1.8
1.6
1.4
1.2
1.
0.8
0.6
0.4
0.2
0.
1.E-002 0.1
1.
10.
100.
1000.
10000
1.E+005
Time [min]


WELL 3923 THEIS METHOD
T = 37.13 ft²/min
S = 0.03156
10.
1.
0.1
1.E-002
1.E-003
1.E-002 0.1 1. 10. 100. 1000. 100001.E+005
Time [min]
Corrected Drawdown [ft]


WELL 3923 COOPER-JACOB METHOD
T = 40.08 ft²/min
S = 0.0198
Corrected Drawdown [ft]
0.
0.2
0.4
0.6
0.8
1.
1.2
1.4
1.6
1.8
2.
1.E-002
0.1
1.
10.
100.
1000.
10000
1.E+005
Time [min]

APPENDIX B

Time-Drawdown Data for Aquifer Tests

OBSERVATION WELL 3910

Pumping rate... 56.82 ft^2/min
Distance to observation well... 47.5 ft
Aquifer saturated thickness... 96 ft
Depth of top of well screen... 4 ft
Depth to bottom of well screen... 44 ft
Hydraulic conductivity ratio (Kz/Kr)... 0.15

Time	Drawdown	Weight
0.05	0.0099995	0.25
0.099	0.019999	0.25
0.148	0.049999	0.25
0.199	0.069998	0.25
0.248	0.099997	0.25
0.298	0.13	0.25
0.347	0.16	0.25
0.397	0.19	0.25
0.446	0.21	0.25
0.513	0.21	0.25
0.546	0.20999	0.25
0.595	0.20999	0.25
0.645	0.19999	0.25
0.694	0.19999	0.25
0.744	0.21	0.25
0.809	0.21999	0.25
0.909	0.22999	0.25
0.942	0.23999	0.25
0.992	0.23999	0.25
1.189	0.24999	0.5
1.388	0.25998	0.5
1.587	0.25998	0.5
1.983	0.26998	0.5
2.578	0.28997	0.5
2.975	0.29996	0.5
3.57	0.30994	0.5
3.966	0.31993	0.5
4.958	0.31992	0.5
5.157	0.30995	0.5
5.95	0.30994	0.5
6.941	0.31993	0.5
7.933	0.31992	0.5
8.924	0.32992	0.5
9.916	0.3399	0.5

11.899	0.37988	1
15.864	0.38984	1
19.832	0.35979	1
25.78	0.38973	1
31.73	0.40967	1
41.65	0.46957	1
51.56	0.45946	1
59.49	0.46938	1
69.41	0.48928	1
79.33	0.53917	1
89.24	0.50907	1
99.16	0.53897	1
153.4	0.5284	1
198.3	0.60793	1
247.4	0.58742	1
297.5	0.6869	1
357	0.67628	1
396.6	0.6587	1
495.8	0.71484	1
596.4	0.72379	1
694.1	0.77277	1
793.25	0.79174	1
1002.4	0.78956	1
1011	0.81947	1
1547	0.85388	1
2003	0.91914	1
2498.8	0.96397	1
2994.5	0.97881	1
3450.7	1.0041	1
4005.9	1.0383	1
4998	1.0879	1
6009	1.1074	1
7001	1.1471	1
7992	1.1668	1
9003	1.2362	1
9995	1.2859	1
10193	1.2738	1

OBSERVATION WELL 3911

Pumping rate.... 56.82 ft^2/min
Distance to observation well... 19.9 ft
Aquifer saturated thickness... 96 ft
Depth of top of well screen... 4 ft
Depth to bottom of well screen... 44 ft
Hydraulic conductivity ratio (Kz/Kr)... 0.15

Time	Drawdown	Weight
0.05	0.0099995	0.25
0.099	0.059999	0.25
0.148	0.11	0.25
0.199	0.17	0.25
0.248	0.24	0.25
0.298	0.29	0.25
0.347	0.36	0.25
0.397	0.4	0.25
0.446	0.43	0.25
0.513	0.43	0.25
0.546	0.42	0.25
0.595	0.4	0.25
0.645	0.39	0.25
0.694	0.39	0.25
0.744	0.4	0.25
0.809	0.41	0.25
0.909	0.44	0.25
0.942	0.45	0.25
1.189	0.47	0.5
1.388	0.47	0.5
1.587	0.47	0.5
1.983	0.48	0.5
2.578	0.49	0.5
2.975	0.5	0.5
3.57	0.5	0.5
3.966	0.5	0.5
4.958	0.51	0.5
5.157	0.51	0.5
5.95	0.5199	0.5
6.941	0.5199	0.5
7.933	0.5199	0.5
8.924	0.5299	0.5
9.916	0.5399	0.5
11.9	0.5799	1

15.86	0.5898	1
19.832	0.5798	1
25.78	0.6197	1
31.73	0.6297	1
41.65	0.6796	1
51.562	0.6695	1
59.494	0.6794	1
69.409	0.6993	1
79.325	0.7392	1
89.241	0.7091	1
99.157	0.729	1
198.31	0.8379	1
297.4	0.8969	1
356.96	0.9063	1
396.63	0.9159	1
495.78	0.9548	1
694.1	1.013	1
793.25	1.042	1
1011.4	1.09	1
2003	1.179	1
2498.8	1.234	1
2994.5	1.259	1
3450.7	1.294	1
4005.9	1.368	1
4997.5	1.428	1
6008.9	1.447	1
7000.5	1.487	1
7992	1.497	1
9003.4	1.556	1
9995	1.606	1
10193	1.584	1

OBSERVATION WELL 3916

Pumping rate... 56.82 ft^2/min
Distance to observation well... 29.2 ft
Aquifer saturated thickness... 96 ft
Depth to top of well screen... 4 ft
Depth to bottom of well screen... 44 ft
Hydraulic conductivity ratio (Kz/Kr)... 0.15

Time	Drawdown	Weight
0.148	0.0099985	0.25
0.199	0.019998	0.25
0.248	0.049997	0.25
0.298	0.069997	0.25
0.347	0.11	0.25
0.397	0.15	0.25
0.446	0.19	0.25
0.513	0.22	0.25
0.546	0.22999	0.25
0.595	0.23999	0.25
0.645	0.23999	0.25
0.694	0.23999	0.25
0.744	0.23999	0.25
0.809	0.24999	0.25
0.909	0.25999	0.25
0.942	0.26999	0.25
0.992	0.27999	0.25
1.189	0.29999	0.5
1.388	0.30999	0.5
1.587	0.31998	0.5
1.983	0.32998	0.5
2.578	0.33997	0.5
2.975	0.33997	0.5
3.57	0.34996	0.5
3.996	0.34996	0.5
4.958	0.35995	0.5
5.157	0.35995	0.5
6.941	0.35994	0.5
7.933	0.35993	0.5
8.924	0.36992	0.5
9.916	0.3799	0.5
11.9	0.40988	1
15.86	0.40984	1
19.83	0.39979	1
25.78	0.42973	1
31.73	0.43967	1
41.65	0.48957	1
51.56	0.47946	1
59.49	0.48938	1
69.41	0.50928	1
79.33	0.53917	1
89.24	0.51907	1

99.16	0.52897	1
198.3	0.59793	1
297.5	0.6569	1
357	0.66628	1
396.6	0.68587	1
495.8	0.70484	1
694.1	0.75277	1
793.3	0.77174	1
1011	0.79947	1
2003	0.83914	1
2499	0.88397	1
2995	0.88881	1
3451	0.90406	1
4006	0.9383	1
4998	0.9679	1
6009	1.007	1
7001	1.027	1
7992	1.037	1
9003	1.106	1

OBSERVATION WELL 3917

Pumping rate... 56.82 ft^2/min
Distance to observation well... 25.1 ft
Aquifer saturated thickness... 96 ft
Depth to top of well screen... 4 ft
Depth to bottom of well screen... 44 ft
Hydraulic conductivity ratio (Kz/Kr)... 0.15

Time	Drawdown	Weight
0.099	0.009999	0.25
0.148	0.0099985	0.25
0.199	0.0099979	0.25
0.248	0.029997	0.25
0.298	0.039997	0.25
0.347	0.069996	0.25
0.397	0.089996	0.25
0.446	0.13	0.25
0.513	0.17	0.25
0.546	0.16999	0.25
0.595	0.18999	0.25
0.645	0.18999	0.25
0.694	0.19999	0.25
0.744	0.20999	0.25
0.809	0.20999	0.25
0.909	0.21999	0.25
0.942	0.22999	0.25
0.992	0.22999	0.25
1.189	0.24999	0.5
1.388	0.26999	0.5
1.587	0.26998	0.5
1.983	0.27998	0.5
2.578	0.29997	0.5
2.975	0.29997	0.5
3.57	0.3	0.5
3.966	0.30996	0.5
4.958	0.31995	0.5
5.157	0.30995	0.5
5.95	0.3099	0.5
6.941	0.30993	0.5
7.933	0.31992	0.5
8.924	0.32991	0.5
9.916	0.3399	0.5
11.9	0.36988	1

15.86	0.36984	1
19.83	0.35979	1
25.78	0.37973	1
31.73	0.37967	1
41.65	0.43957	1
51.56	0.44946	1
59.49	0.45938	1
69.41	0.46928	1
79.33	0.50917	1
89.24	0.47907	1
99.16	0.49897	1
198.3	0.55793	1
297.5	0.6269	1
357	0.63628	1
396.6	0.65587	1
495.8	0.67484	1
694.1	0.72277	1
793.3	0.73174	1
1011	0.75946	1
2003	0.84914	1
2499	0.89397	1
2995	0.91881	1
3451	0.93406	1
4006	0.96827	1
4998	1.0079	1
6009	1.0474	1
7001	1.0671	1
7992	1.0968	1
9003	1.1562	1
9995	1.2059	1
10193	1.1938	1

OBSERVATION WELL 3918

Pumping rate... 56.82 ft^2/min
Distance to observation well... 24.3 ft
Aquifer saturated thickness... 96 ft
Depth to top of well screen... 4 ft
Depth to bottom of well screen... 44 ft
Hydraulic conductivity ratio (Kz/Kr)... 0.15

Time	**Drawdown**	**Weight**
0.199	0.0099979	0.25
0.248	0.019997	0.25
0.298	0.029997	0.25
0.347	0.039996	0.25
0.397	0.069996	0.25
0.446	0.089995	0.25
0.513	0.12	0.25
0.546	0.12999	0.25
0.595	0.13999	0.25
0.645	0.14999	0.25
0.694	0.15999	0.25
0.744	0.15999	0.25
0.809	0.17	0.25
0.909	0.17	0.25
0.942	0.18	0.25
0.992	0.18	0.25
1.189	0.19999	0.5
1.388	0.20999	0.5
1.587	0.21998	0.5
1.983	0.22998	0.5
2.578	0.22997	0.5
2.975	0.23997	0.5
3.57	0.23996	0.5
3.996	0.24996	0.5
4.958	0.25995	0.5
5.157	0.25994	0.5
6.941	0.25993	0.5
7.933	0.26992	0.5
8.924	0.26991	0.5
9.916	0.2799	0.5
11.9	0.29988	1
15.86	0.30984	1
19.83	0.29979	1
25.78	0.32973	1

31.73	0.33967	1
41.65	0.37957	1
51.56	0.37946	1
59.49	0.38938	1
69.41	0.39928	1
79.33	0.43917	1
89.24	0.40907	1
99.16	0.42897	1
198.3	0.48793	1
297.5	0.5469	1
357	0.5563	1
396.6	0.57587	1
495.8	0.59484	1
694.1	0.64278	1
793.3	0.6617	1
1011	0.68947	1
2003	0.77914	1
2499	0.82397	1
2995	0.83881	1
3451	0.86406	1
4006	0.89827	1
4998	0.93794	1
6009	0.96741	1
7001	0.98708	1
7992	0.99675	1
9003	1.0462	1
9995	1.0559	1
10193	1.0438	1

OBSERVATION WELL 3921

Pumping rate... 56.82 ft^2/min
Distance to observation well... 48.3 ft
Aquifer saturated thickness... 96 ft
Depth to top of well screen... 4 ft
Depth to bottom of well screen... 44 ft
Hydraulic conductivity ratio (Kz/Kr)... 0.15 ft

Time	Drawdown	Weight
0.099	0.009999	0.25
0.148	0.019999	0.25
0.199	0.029998	0.25
0.248	0.059997	0.25
0.298	0.069997	0.25
0.347	0.099996	0.25
0.397	0.13	0.25
0.446	0.15	0.25
0.513	0.18	0.25
0.546	0.18	0.25
0.595	0.18	0.25
0.645	0.18	0.25
0.694	0.18	0.25
0.744	0.18	0.25
0.809	0.19	0.25
0.909	0.2	0.25
0.942	0.21	0.25
0.992	0.21	0.25
1.189	0.22	0.5
1.388	0.23	0.5
1.587	0.24	0.5
1.983	0.24	0.5
2.578	0.26	0.5
2.975	0.26	0.5
3.57	0.26	0.5
3.966	0.27	0.5
4.958	0.27	0.5
5.157	0.28	0.5
5.95	0.2899	0.5
6.941	0.2899	0.5
7.933	0.2999	0.5
8.924	0.2999	0.5
9.916	0.3099	0.5
11.9	0.3399	1

15.86	0.3598	1
19.83	0.3398	1
25.78	0.3697	1
31.73	0.3797	1
41.65	0.4496	1
51.56	0.4395	1
59.49	0.4594	1
69.41	0.4693	1
79.33	0.5092	1
89.24	0.4891	1
99.16	0.519	1
198.3	0.5579	1
297.4	0.6169	1
357	0.6063	1
396.6	0.6259	1
495.8	0.6648	1
694.1	0.6928	1
793.3	0.7217	1
1011	0.7495	1
2003	0.8391	1
2499	0.874	1
2995	0.8988	1
3451	0.9141	1
4006	0.9683	1
4998	1.008	1
6009	1.047	1
7001	1.077	1
7992	1.077	1
9003	1.156	1
9995	1.206	1
10193	1.204	1

OBSERVATION WELL 3922

Pumping rate... 56.82 ft^2/min
Distance to observation well... 199.4 ft
Aquifer saturated thickness... 96 ft
Depth to top of well screen... 4 ft
Depth to bottom of well screen... 44 ft
Hydraulic conductivity ratio (Kz/Kr)... 0.15

Time	**Drawdown**	**Weight**
1.189	0.0099876	0.5
1.388	0.0099855	0.5
1.587	0.0099835	0.5
1.983	0.019979	0.5
2.578	0.019973	0.5
2.975	0.019969	0.5
3.57	0.029948	0.5
3.966	0.019959	0.5
4.958	0.029948	0.5
5.157	0.029946	0.5
5.95	0.039938	0.5
6.941	0.039928	0.5
7.933	0.039917	0.5
8.924	0.039907	0.5
9.916	0.049897	0.5
11.899	0.089876	1
15.864	0.079835	1
19.832	0.019793	1
25.78	0.079732	1
31.73	0.06967	1
41.646	0.13957	1
51.562	0.11946	1
59.494	0.12938	1
69.409	0.12928	1
79.325	0.17917	1
89.251	0.13907	1
99.157	0.14897	1
198.31	0.20793	1
297.47	0.2669	1
356.96	0.26628	1
396.63	0.27587	1
495.78	0.30485	1
694.1	0.35277	1
793.25	0.36174	1

1011.4	0.38947	1
2003	0.48914	1
2498.8	0.53397	1
2994.5	0.54881	1
3450.7	0.57406	1
4005.9	0.61827	1
4997.5	0.54881	1
6008.9	0.68741	1
7001	0.65794	1
7992	0.71708	1
9003	0.79621	1
9995	0.84589	1

OBSERVATION WELL 3923

Pumping rate... 56.82 ft^2/min
Distance to observation well... 49.2 ft
Aquifer saturated thickness... 96 ft
Depth of top of well screen... 4 ft
Depth to bottom of well screen... 44 ft
Hydraulic conductivity ratio (Kz/Kr)... 0.15

Time	**Drawdown**	**Weight**
0.05	0.0099995	0.25
0.099	0.019999	0.25
0.148	0.049999	0.25
0.199	0.069998	0.25
0.248	0.099997	0.25
0.298	0.13	0.25
0.347	0.16	0.25
0.397	0.19	0.25
0.446	0.21	0.25
0.513	0.21	0.25
0.546	0.20999	0.25
0.595	0.20999	0.25
0.645	0.19999	0.25
0.694	0.19999	0.25
0.744	0.21	0.25
0.809	0.21999	0.25
0.909	0.22999	0.25
0.942	0.23999	0.25
0.992	0.23999	0.25
1.189	0.24999	0.5
1.388	0.25998	0.5
1.587	0.25998	0.5
1.983	0.26998	0.5
2.578	0.28997	0.5
2.975	0.29996	0.5
3.57	0.30994	0.5
3.966	0.31993	0.5
4.958	0.31992	0.5
5.157	0.30995	0.5
5.95	0.30994	0.5
6.941	0.31993	0.5
7.933	0.31992	0.5
8.924	0.32992	0.5
9.916	0.3399	0.5

11.899	0.37988	1
15.864	0.38984	1
19.832	0.35979	1
25.78	0.38973	1
31.73	0.40967	1
41.65	0.46957	1
51.56	0.45946	1
59.49	0.46938	1
69.41	0.48928	1
79.33	0.53917	1
89.24	0.50907	1
99.16	0.53897	1
153.4	0.5284	1
198.3	0.60793	1
247.4	0.58742	1
297.5	0.6869	1
357	0.67628	1
396.6	0.6587	1
495.8	0.71484	1
596.4	0.72379	1
694.1	0.77277	1
793.25	0.79174	1
1002.4	0.78956	1
1011	0.81947	1
1547	0.85388	1
2003	0.91914	1
2498.8	0.96397	1
2994.5	0.97881	1
3450.7	1.0041	1
4005.9	1.0383	1
4998	1.0879	1
6009	1.1074	1
7001	1.1471	1
7992	1.1668	1
9003	1.2362	1
9995	1.2859	1
10193	1.2738	1

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